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Air Conditioning Heat load Analysis of a Cabin

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Abstract: Air conditioning, often abbreviated as A/C (US), AC (US), or air con (UK), is the process of removing heat from an enclosed space to achieve a more comfortable interior environment (sometimes referred to as "comfort cooling") and in some cases also strictly controlling the humidity of internal air. Air conditioning can be achieved using a mechanical 'air conditioner' or alternatively a variety of other methods, including passive cooling or ventilative cooling. Air conditioning is a member of a family of systems and techniques that provide heating, ventilation, and air conditioning (HVAC). Heat pumps are similar in many ways to air conditioners, but use a reversing valve to allow them to heat and also cool an enclosed space.

Air conditioners, which typically use vapor-compression refrigeration, range in size from small units used within vehicles or single rooms to massive units that can cool large buildings. Air source heat pumps, which can be used for heating as well as cooling, are becoming increasingly common in cooler climates.

According to the International Energy Agency (IEA), as of 2018, 1.6 billion air conditioning units were installed, which accounted for an estimated 20% of electricity usage in buildings globally with the number expected to grow to 5.6 billion by 2050. The United Nations called for the technology to be made more sustainable to mitigate climate change and for the use of alternatives, like passive cooling, evaporative cooling, selective shading, windcatchers, and better thermal insulation. CFC and HCFC refrigerants such as R-12 and R-22, respectively, used within air conditioners have caused damage to the ozone layer, and HFC refrigerants such as R-410a and R-404a, which were designed to replace CFCs and HCFCs, are instead exacerbating climate change.

Both issues happen due to the venting of refrigerant to the atmosphere, such as during repairs. HFO refrigerants, used in some if not most new equipment, solve both issues with an ozone damage potential (ODP) of zero and a much lower global warming potential (GWP) in the single or double digits vs. the three or four digits of HFCs.

Keywords: Heat Balance Method, Transport aircraft, Automobile, Air Conditioning, Environmental, HFO refrigerants

I. INTRODUCTION

In 1558, Giambattista della Porta described a method of chilling ice to temperatures far below its freezing point by mixing it with potassium nitrate (then called "nitre") in his popular science book Natural Magic. In 1620, Cornelis Drebbel demonstrated "Turning Summer into Winter" for James I of England, chilling part of the Great Hall of Westminster Abbey with an apparatus of troughs and vats. Drebbel's contemporary Francis Bacon, like della Porta a believer in science communication, may not have been present at the demonstration, but in a book published later the same year, he described it as "experiment of artificial freezing" and said that "Nitre (or rather its spirit) is very cold, and hence nitre or salt when added to snow or ice intensifies the cold of the latter, the nitre by adding to its own cold, but the salt by supplying activity to the cold of the snow."

In 1758, Benjamin Franklin and John Hadley, a chemistry professor at University of Cambridge, conducted an experiment to explore the principle of evaporation as a means to rapidly cool an object. Franklin and Hadley confirmed that the evaporation of highly volatile liquids (such as alcohol and ether) could be used to drive down the temperature of an object past the freezing point of water. They conducted their experiment with the bulb of a mercury-in-glass thermometer as their object and with a bellows used to speed up the evaporation. They lowered the temperature of the thermometer bulb down to −14 °C (7 °F) while the ambient temperature was 18 °C (64 °F). Franklin noted that soon after they passed the freezing point of water 0 °C (32 °F), a thin film of ice formed on the surface of the thermometer's bulb and that the ice mass was about 6 mm (1⁄4 in) thick when they stopped the experiment upon reaching −14 °C (7 °F). Franklin concluded: "From this experiment one may see the possibility of freezing a man to death on a warm summer's day."

The 19th century included a number of developments in compression technology. In 1820, English scientist and inventor Michael Faraday discovered that compressing and liquefying ammonia could chill air when the liquefied ammonia was allowed to evaporate. In 1842, Florida physician John Gorrie used compressor technology to create ice, which he used to cool air for his patients in his hospital in Apalachicola, Florida.

He hoped to eventually use his ice-making machine to regulate the temperature of buildings and envisioned centralized air conditioning that could cool entire cities. Gorrie was granted a patent in 1851, but following the death of his main backer he was not able to realise his invention. In 1851, James Harrison created the first mechanical ice-making machine in Geelong, Australia, and was granted a patent for an ether vapor-compression refrigeration system in 1855 that produced three tons of ice per day. In 1860, Harrison established a second ice company and later entered the debate over how to compete against the American advantage of ice-refrigerated beef sales to the United Kingdom.

Innovations in the latter half of the 20th century allowed for much more ubiquitous air conditioner use. In 1945, Robert Sherman of Lynn, Massachusetts invented a portable, in-window air conditioner that cooled, heated, humidified, dehumidified, and filtered the air.

As international development has increased wealth across countries, global use of air conditioners has increased. By 2018, an estimated 1.6 billion air conditioning units were installed worldwide, with the International Energy Agency expecting this number to grow to 5.6 billion units by 2050. Between 1995 and 2004, the proportion of urban households in China with air conditioners increased from 8% to 70%. As of 2015, nearly 100 million homes, or about 87% of US households, had air conditioning systems. In 2019, it was estimated that 90% of new single-family homes constructed in the USA included air conditioning (ranging from 99% in the South to 62% in the West).

The most important aspect of ECS is to know the cabin heat loads during air cooling or air heating phases. A precise calculation of aircraft heat load would be a long process requiring detailed knowledge of the aircraft structure and of the quantities involved in the mechanism of heat pick up and interchange in the cabin. However, it is possible to make a sufficiently accurate estimate using mean quantities for calculating the heat transfer process providing we know the essential details of the cabin structure such as the transparency areas and the external wall areas and whether or not the aircraft is to be insulated.

ASHRAE Handbook of Fundamentals provides two major thermal load calculation methodologies: Heat Balance Method (HBM) and Weighting Factor Method (WFM). HBM is the most scientifically rigorous available method and can consider more details with less simplifying assumptions. An advantage of HBM is that several fundamental models can be incorporated in the thermal calculations. Although HBM is more accurate than WFM, it is easier to implement WFM for load calculation in a passenger room. However, when more detailed information of the room body and thermal loads is available, HBM is the preferred choice. Curtis O. Pedersen paper has presented a complete formulation of a heat balance procedure for determining cooling loads.

From this paper how heat balance is formulated to calculate cooling load is studies. Zheng.Y devised a simple method to calculate room's thermal loads. They calculated the different loads such as the radiation and ambient loads. A case study was performed and the results were validated using wind tunnel climate control tests. The different loads were separately calculated and summed up to give the total heat gain or loss from the cabin. Ergonomics of the Thermal Environment - Determination of Metabolic Heat Production provides passenger metabolic heat production rate based on various criteria such as occupation and activity levels. Huajun Zhang analyze the temperature and air-flow field inside the passenger compartment to ameliorate the amenity and decrease energy consumption.

II. TYPES OF AIR CONDITIONER

A. *Window Unit And Packaged Terminal*

The packaged terminal air conditioner (PTAC), through-the-wall, and window air conditioners are similar. PTAC systems may be adapted to provide heating in cold weather, either directly by using an electric strip, gas, or other heaters, or by reversing the refrigerant flow to heat the interior and draw heat from the exterior air, converting the air conditioner into a heat pump. They may be installed in a wall opening with the help of a special sleeve on the wall and a custom grill that is flush with the wall and window air conditioners can also be installed in a window, but without a custom grill.

Fig a) Window unit and packaged terminal

B. Ducted Central Systems

Split-system central air conditioners consist of two heat exchangers, an outside unit (the condenser) from which heat is rejected to the environment and an internal heat exchanger (the fan coil unit (FCU), air handling unit, or evaporator) with the piped refrigerant being circulated between the two. The FCU is then connected to the spaces to be cooled by ventilation ducts. This paper uses commercial software FLUENT to simulate 3-D temperature distributions and flow field in a compartment with or without passengers. He suggested that the air flow and temperature fields are definitely the most important factors that contribute to thermal comfort. Ozgur Solmaz uses Artificial Neural Networks (ANNs) method for prediction hourly cooling load of a room. He suggested that ANN method can be very effective as it is simpler and does not use so many input parameters like the analytical model.

C. Central Plant Cooling

Large central cooling plants may use intermediate coolant such as chilled water pumped into air handlers or fan coil units near or in the spaces to be cooled which then duct or deliver cold air into the spaces to be conditioned, rather than ducting cold air directly to these spaces from the plant, which is not done due to the low density and heat capacity of air which would require impractically large ducts. The chilled water is cooled by chillers in the plant, which uses a refrigeration cycle to cool water, often transferring its heat to the atmosphere even in liquid-cooled chillers through the use of cooling towers. Chillers may be air or liquid-cooled.

D. Portable Units

A portable system has an indoor unit on wheels connected to an outdoor unit via flexible pipes, similar to a permanently fixed installed unit (such as a ductless split air conditioner). Hose systems, which can be monoblock or air-to-air, are vented to the outside via air ducts. The monoblock type collects the water in a bucket or tray and stops when full. The air-to-air type re-evaporates the water and discharges it through the ducted hose and can run continuously. Such portable units draw indoor air and expel it outdoors through a single duct, which negatively impacts their overall cooling efficiency. Many portable air conditioners come with heat as well as a dehumidification function.

E. Mini-Split And Multi-Split Systems

Ductless systems (often mini-split, though there are now ducted mini-split) typically supply conditioned and heated air to a single or a few rooms of a building, without ducts and in a decentralized manner. Multi-zone or multi-split systems are a common application of ductless systems and allow up to eight rooms (zones or locations) to be conditioned independently from each other, each with its own indoor unit and simultaneously from a single outdoor unit.

F. Packaged Air Conditioner

Packaged air conditioners (also known as self-contained units)are central systems that integrate into a single housing all the components of a split central system, and deliver air, possibly through ducts, to the spaces to be cooled. Depending on their construction they may be outdoors or indoors, on roofs (rooftop units), draw the air to be conditioned from inside or outside a building and be water, refrigerant or air-cooled. Often, outdoor units are air-cooled while indoor units are liquid-cooled using a cooling tower.

III. OBJECTIVES

1) To calculate the sensible and latent Heat gain from occupants.
2) To calculate the Heat load of cabin area.
3) To calculate the total cabin load with respect to study of Human Comfort.

IV. PROPOSED SYSTEM ELEMENTS

The Component Effects section presents flow quality and flow regime results, and discusses the influence of system components on flow quality and flow regimes in the condenser and evaporator. The condenser heat exchanger is a serpentine-type design with 6 serpentine passes, 10 parallel channels, and a weight of 11 lbms. The tube diameter was an optimization variable and determined as discussed in the following section on system optimization. The evaporator heat exchanger is also a serpentine-type design with 12 serpentine passes, a tube diameter of 0.0625 inch, and a weight of 6.6 lbms. The heat exchangers were typical of designs shown in Kargilis.

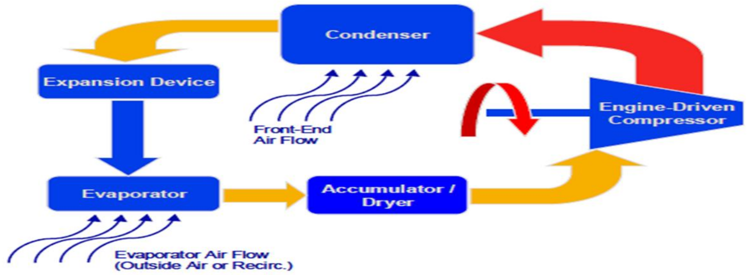

Fig b) – Schematic Diagram of a Typical existing Air Conditioning System

The transport lines shown in Figure c) between the compressor and condenser and between the condenser and the expansion device are critical components in the A/C system design. Their diameter and length impact system performance. Compressor characteristics and orifice diameter are other key system parameters that impact transient system performance. The System Optimization Studies section will demonstrate how this component design is important to optimizing system COP and inter-dependent on other important system components, particularly the condenser.

V. HEAT LOAD ANALYSIS

A Heat Load Analysis is the method used to figure out how much heating and cooling a home needs to stay comfortably cool in the summer and warm in the winter. It is used to determine the size of the HVAC system a building needs and what sort of energy cost your home should have.

Fig c) Heat load analysis

A. How a Heat Load Analysis Can Benefit Homeowners

When it comes to HVAC systems, the biggest system isn't always the best for a home. Different sized systems operate most efficiently at different load levels, so the ideal size of a system needs to be identified for every given home. The result of a heat load analysis is what we use to determine the size of the HVAC system that your home needs.

An oversized HVAC system causes two big issues: inefficiency and air quality problems. When a system is too big or too small for the job, it ends up working harder than a properly sized one, and that means it will draw a lot more power than it should to cool or heat your home. Considering that air conditioning is usually the largest part of your energy bill, this is extremely important.

Oversized HVAC systems don't just draw too much power trying to run low, they also can't dehumidify the air properly. Humidity control relies on the system running optimally. Not only will that overpowered air conditioning system cost too much, it can result in overly humid air, making life more uncomfortable in your home.

B. What can be Done to Improve a Home's Heat Load

No home can be perfectly insulated from the outside temperature, but there are lots of possible improvements you can make to reduce your home's heat load.

1) Get a heat load analysis performed and find out your home's air conditioning needs
2) Improve and maintain your insulation, especially in the ceilings, ducts, and floors
3) Shade your windows to prevent direct sunlight from warming up your home
4) Use energy-efficient lightbulbs, which generate less heat than incandescent bulbs
5) Don't leave exterior doors and windows open when they don't need to be.

C. Formula for Specific Heat

The first step in selecting the proper product for your cooling system application is to determine the heat load, or the amount of heat generated by your system. This article explains how to establish heat load for any liquid cooling application.

A quick and dirty method of estimating heat load is to assume that all electrical energy entering a process is converted to heat. From the 1st Law of Thermodynamics we know that the amount of energy exiting a system can never be greater than the amount of energy entering a system. The heat load can be conservatively estimated to be equal to the amount of electricity consumed if electricity is the only form of energy entering a system.

To determine heat load more accurately, the equation $Q = m \times Cp \times \Delta T$ can be used where:

Q = heat load (BTU/hr)
m = mass flow rate (lb/hr)
Cp = specific heat (BTU/lb °F)
ΔT = change in temperature (°F)

D. Heat load calculations

There are several different methods of calculating the heat load for a given area:

Quick calculation for offices

For offices with average insulation and lighting, 2/3 occupants and 3/4 personal computers and a photocopier, the following calculations will suffice:

Heat load (BTU) = Length (ft.) x Width (ft.) x Height (ft.) x 4

Heat load (BTU) = Length (m) x Width (m) x Height (m) x 141

For every additional occupant add 500 BTU.

If there are any additional significant sources of heat, for instance floor to ceiling south facing windows, or equipment that produces lots of heat, the above method will underestimate the heat load. In which case the following method should be used instead.

The heat gain of a room or building depends on:

1) The size of the area being cooled
2) The size and position of windows, and whether they have shading
3) The number of occupants
4) Heat generated by equipment and machinery
5) Heat generated by lighting

By calculating the heat gain from each individual item and adding them together, an accurate heat load figure can be determined.

a) Step One

Calculate the area in square feet of the space to be cooled, and multiply by 31.25

Area BTU = length (ft.) x width (ft.) x 31.25

b) Step Two

Calculate the heat gain through the windows. If the windows don't have shading multiply the result by 1.4

North window BTU = Area of North facing windows (m. sq.) x 164

If no shading, North window BTU = North window BTU x 1.4

South window BTU = Area of South facing windows (m. sq.) x 868

If no shading, South window BTU = South window BTU x 1.4

Add the results together.

Total window BTU = North window + South window

c) Step Three

Calculate the heat generated by occupants, allow 600 BTU per person.

Occupant BTU = number of people x 600

d) Step Four

Calculate the heat generated by each item of machinery - copiers, computers, ovens etc. Find the power in watts for each item, add them together and multiply by 3.4

Equipment BTU = total equipment watts x 3.4

e) Step Five

Calculate the heat generated by lighting. Find the total wattage for all lighting and multiply by 4.25

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Lighting BTU = total lighting watts x 4.25

f) Step Six

Add the above together to find the total heat load.

Total heat load BTU = Area BTU + Total Window BTU + Occupant BTU + Equipment BTU + Lighting BTU

g) Step Seven

Divide the heat load by the cooling capacity of the air conditioning unit in BTU, to determine how many air conditioners are needed.

Number of a/c units required = Total heat load BTU / Cooling capacity BTU

HEAT LOAD CALCULATIONS SHEET

ROOM SENSIBLE LOAD

TYPE	AREA (Sq. ft.)		TEMP. DEFF. (F°)		FACTOR		BTUH
SOLAR GAIN-GLASS							
NORTH	0	x	23	x	0.36	=	0
SOUTH		x	12	x	0.36	=	0
EAST	138	x	12	x	0.36	=	596
WEST		x	163	x	0.36	=	0
N-E		x	12	x	0.36	=	0
N-W		x	138	x	0.36	=	0
S-E		x	12	x	0.36	=	0
S-W		x	85	x	0.36	=	0
SKYLIGHT		x	118	x	0.36	=	0
Sub. Total	138						596
SOLAR & TRANS. GAIN - WALLS & ROOF							
NORTH		x	22	x	0.36	=	0
SOUTH		x	34	x	0.36	=	0
EAST		x	36	x	0.36	=	0
WEST		x	30	x	0.36	=	0
N-E		x	28	x	0.36	=	0
N-W		x	24	x	0.36	=	0
S-E		x	36	x	0.36	=	0
S-W		x	32	x	0.36	=	0
ROOF			53		0.4	=	0
Sub. Total							0
TRANSMISSION GAIN (EXCEPT WALL AND ROOF)							
ALL GLASS	138	x	36	x	1.13	=	5614
PART	142	x	31	x	0.41	=	1805
CEIL	0	x	31	x	0.44	=	0
FLOOR	0	x	31	x	0.44	=	0
Sub. Total							7419

BYPASS O.A. SENSIBLE LOAD	cfm	TEMP. DEFF. (F°)	BYPASS COIL	FACTOR AIR	BTUH
Ventilation Air / Fresh Air	25	36	0.12	1.08	117
Sub. Total					117

INTERNAL SENSIBLE LOAD							
	No. of People		FACTOR				BTUH
PEOPLE	4	x	245			=	980
Sub. Total							
	WATTS		FACTOR				BTUH
APPLIANCES	30	x	3.41			=	102
LIGHTS	2	x	3.41	+	1.2	=	8
Sub. Total							110
Total (SENSIBLE LOAD)							9223
LEAK LOSS +SAFETY FACTOR=				12.50%			1153
TOTAL ROOM SENSIBLE HEAT (RSH)							10375

ROOM LATENT LOAD

BYPASS O.A. LATENT LOAD	CFM	G.DIFF	BYPASS COIL	FACTOR AIR	BTUH
Ventilation Air / Fresh Air	25	6.5	0.12	0.68	13
Sub. Total					13

INTERNAL LATENT LOAD					
	No. of People		FACTOR		BTUH
PEOPLE	4	x	205		820
Sub. Total					820
Total (LATENT LOAD)					833
SAFETY FACTOR=				5%	42
TOTAL ROOM LATENT HEAT (RLH)					875

ROOM TOTAL HEAT

	RSH	+	RLH	=	BTUH
ROOM TOTAL HEAT	10375	+	875	=	11250

OTHER HEAT

OUTSIDE AIR HEAT	CFM	G.DIFF	1-B.F.	FACTOR AIR	BTUH
SENS	25	36	0.88	1.08	861
LAT	25	6.5	0.88	0.68	98
OUTSIDE AIR HEAT					959

GRAND TOTAL HEAT

	ROOM TOTAL HEAT	+	OTHER HEAT	=	BTUH
TOTAL HEAT	11250	+	959	=	12209
HEAT GAIN SAFETY FACTOR =			3%		366
GRAND TOTAL HEAT	(TONS)		1.0	TR	12575

DEHUMIDIFIED AIR Cfm

SENSIBLE HEAT FACTOR	ROOM SENSIBLE LOAD / ROOM TOTAL HEAT	=	0.92
SELECTED A.D.P.			

DESIGN IN PUT DATA

AREA	=	152.610156
HT.OF THE AREA	=	12
LIGHTING (WATTS/SQFT)	=	1
APPLIANCES	=	30
SQFT / PEOPLE	=	40 to 50
NO.OF PEOPLE	=	4
APPLICATION	=	
PEOPLE FACTOR OF SENSIBLE	=	245
PEOPLE FACTOR OF LATENT	=	205
Type of AC system	=	Window AC
CFM per TR	=	400
ADP	=	56

OUTSIDE & INSIDE DESIGN DATA

CITY:	Nagpur	Daily Rang	26	°F
CORRECTIONS FACTOR	18	Lattitude	18.32	
AREA	D.B.	W.B.	%RH	GR/LB *
OUTSIDE	112	76	18	73.70
INSIDE	76	63	50	67.2
DIFF.	36	13		7
HRW DATA				
AIR FROM HRW				
INSIDE				
DIFF.				
* Value come from Psychromeric Chart				

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Base on Area		
cfm per Sqft	=	0.06
Cfm as per AREA	=	9
Base on People		
Cfm/PERSON	=	4
Cfm as per People	=	16
Total Cfm		
Total Cfm=Area CFM+People CFM	=	25.2
Total Cfm as per LEED		
30% Extra Cfm (as per LEED)	=	
Cfm as per 30% Extra Cfm	=	
Final Cfm=Total CFM+30%CFM	=	

HEAT LOAD SUMMARY

GRAND TOTAL HEAT	1.0	TR
DEHUMIDIFIED AIR Cfm	546	CFM
TONS AS PER Cfm	1.4	TR
TONNAGE REQUIRED	1.4	TR

CHECK RESULTS.

AREA PER TON	111.84	SQFT.
CFM PER SQFT	3.58	CFM
GRAND TOTAL HEAT(BTU/HR/SQFT.)	82.40	BTUH
ROOM SENSIBLE HEAT(BTU/HR/SQFT.)	67.99	BTUH
SQFT/PERSON	38.15	SQFT.
TONS PER SQFT	0.01	TR
TONS/PERSON	0.34	TR
DEHUMIDIFIED CFM/TON	400.00	CFM

GLASS	0.60	TR	57.22%
WALL/ROOF/CEIL/FLOOR	0.00	TR	0.00%
LIGHTING	0.00	TR	0.07%
PEOPLE	0.17	TR	16.08%
EQUIPMENT	0.01	TR	0.94%
FRESHAIR	0.09	TR	9.05%

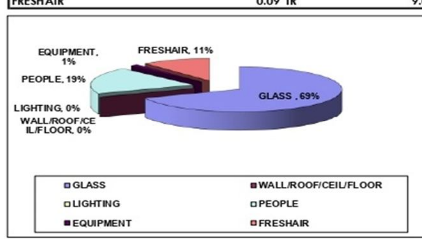

Fig d) Heat load analysis

VI. CONCLUSIONS

In order to preserve users' thermal comfort, mobile air conditioning systems should be built to account for the constant variations in the cabin thermal loads. In this study, the various heating and cooling loads supplied to a cabin via radiation, convection, and conduction are modelled using the Heat Balance Method (HBM). Calculations of the various load categories are done using mathematical models of heat transfer phenomena. A thorough heat balancing model is created for use in the development of mobile air conditioning systems. A brand-new, all-inclusive AC design tool is created. A comprehensive stand-alone model of load estimation is developed from mathematical load calculation models that are developed and gathered from diverse sources.

A continual time-stepping is carried out while making the assumptions of a quasi-steady state and lumped bodies, Total heat gain (or loss) experienced by the cabin air after each time step causes the cabin air temperature to change in accordance. After each time step, cabin wall temperatures are updated as well. The shape of the vehicle, the qualities of the materials, and the characteristics of the driving situation are inputs into the current computer simulation. The correlations inside the model can be improved by incorporating data from upcoming research from numerical simulations or experimental tests. For instance, in order to obtain trustworthy findings, the heat transfer coefficient on every area of the cabin surface might be connected with simulations carried out especially on a given vehicle.

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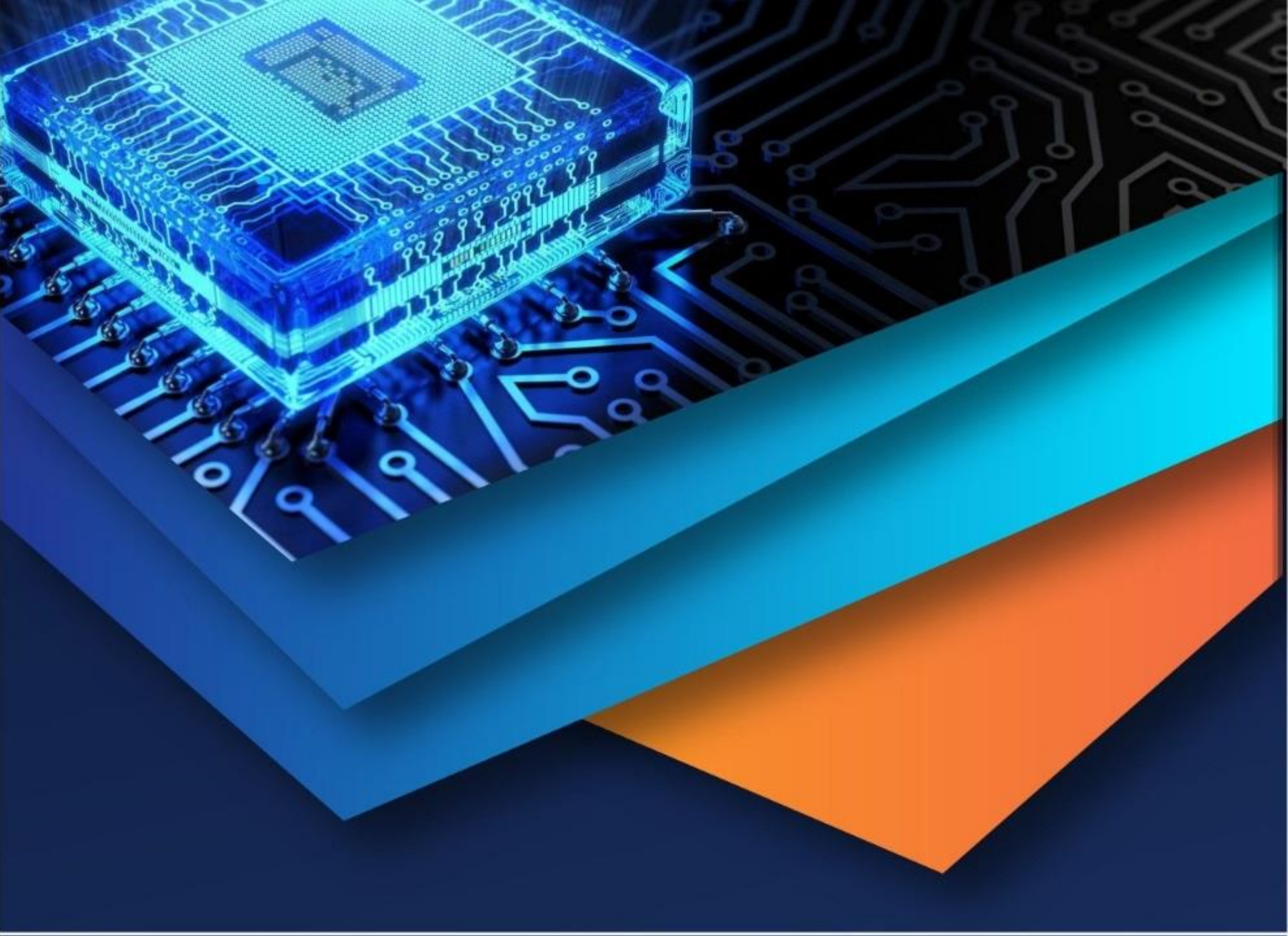

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