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ADVANCING ENERGY CONSERVATION AND SUSTAINABLE BUILDING PRACTICES THROUGH COMPREHENSIVE THERMAL-COOLING LOAD ANALYSIS IN AIRPORT BUILDING

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Abstract

The global discussion on conserving energy's importance has persisted, paralleling the surge in energy use over two decades. This rise presents challenges for local energy supply to diverse buildings. Designing energy-efficient buildings has become crucial in reducing energy usage and promoting sustainability. This research comprehensively analyzed and assessed thermal-cooling loads within an airport building using Panasonic software. The investigation primarily focuses on evaluating cooling load and thermal dynamics within the airport facility, emphasizing enhancing energy efficiency, and ensuring thermal comfort. Additionally, duct sizing design was conducted to achieve a comprehensive HVAC installation. From the result of the investigation, it was found that the highest Cooling Load at the airport occurs at 4:00 PM, aligning with the peak temperature resulting from heat transmitted into the building, reaching 263,591 Watts for the Airport Lounge and 82,202 Watts for the Luggage Room. Building energy management must be undertaken to minimize the energy consumption during that period. By thoroughly examining thermal-cooling loads within an airport building, this research contributes to decision-making for designing and operating HVAC systems, thereby advancing sustainable building practices.

Keywords: HVAC System, Airport Building, Cooling Load, Panasonic Heat Load Software, Duct Sizing

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1. Introduction

Buildings represent a significant portion of the world's energy needs, generating CO^2 gas emissions. The emissions produced by this building sector reach over 35%, surpassing the transportation and industrial sectors[1]. It is due to the fact that CO^2 emissions from buildings are quantified at various stages of the life cycle, such as building material preparation, construction operation, demolition, and waste disposal, which affects the magnitude of the CO^2 contribution generated by the building sector[2, 3]. Energy usage becomes substantial, particularly in sizable commercial structures that are air-conditioned, like airports, offices, retail establishments, and similar venues. Most of the electricity generated by these large commercial buildings can exceed 1 GWh [4]. Approximately 60% of the total energy consumption in the building sector comes from HVAC (Heating, Ventilation, and Air Conditioning) needs[5-7]. Meanwhile, the remaining 40% comes from the lighting system, equipment and appliances, ventilation and air exchange, occupancy, and maintenance.

The meticulous planning of cooling and heating requirements, efficient orchestration of HVAC operations, and the meticulous design of the air distribution system to meet cooling load needs are pivotal in diminishing energy consumption[8]. The values derived from these calculations will influence equipment selection and duct design to deliver comfortable airflow for humans. Consequently, this will ultimately impact energy efficiency, human well-being, indoor air quality, and the resilience of the building[9].

Numerous factors influence the cooling load of a building, encompassing both external and internal elements. The climate influences external factors, while internal factors are influenced by the characteristics within the building, including the building envelope, occupancy pattern, and operating schedules[10, 11]. Several standards have been published by ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers) for estimating the cooling load within buildings, as outlined in ASHRAE Standard 183[12]. Currently, many engineers employ various computer software applications to simulate the energy performance of substantial commercial buildings.

This cooling load is mainly determined by three primary heat transfer mechanisms: radiation, convection, and conduction via heat transmission in walls, windows, and roofs[13]. Air infiltration occurs in open gap areas such as doors and windows. Internal loads include people, lighting, and equipment. To achieve green building and reduce energy consumption, obtaining an accurate cooling load within a building is essential, especially since external and internal environmental factors also significantly contribute to the increase in the cooling load.

An efficiently operated HVAC system within a building can elevate the Energy Performance Index (EPI) to as high as 120 kWh/sq.m per year[14]. Hence, the current trajectory of HVAC technology is shifting towards achieving higher energy efficiency levels, with the goal of attaining a Green Building Leadership in Energy and Environmental Design (LEED) rating [14]. It is also performed by Yadav et al., who utilized the CLTD (Cooling Load Temperature Difference) method to estimate the cooling load of an educational research institute[15]. Their design has succeeded in reducing power consumption and lowering the capital costs. Additionally, Rawal et al. investigated the evaluation of building envelope parameters and overall heat transfer coefficients to examine their impact on thermal comfort[16]. Kulkarni et al. conducted further optimization of the annual cooling capacity for a lecture theatre in India using a computer simulation program[17]. Despite the various investigations into cooling load capacity, a significant portion of research still needs to be focused on calculating the total cooling load, often neglecting peak and static load considerations within the total cooling load. However, conducting observations during critical hours is crucial to optimize and manage energy usage to achieve energy savings. Furthermore, existing investigations still need more discussion on the design of air distribution systems for efficient air conditioning. Therefore, this study focuses on estimating the thermal load of a large commercial building, specifically an airport, aiming to determine the optimal placement of air-conditioning equipment to ensure comfortable operation and optimal air distribution within the air-conditioned zone. Comprehensive cooling load calculations are carried out for each section of the building, encompassing an overall calculation of the building's load. HVAC designers and consultants can leverage these findings to offer technical recommendations, thereby achieving optimal system performance.

2. Methodology

2.1 Building Description

The building description for cooling load refers to detailed information and characteristics of a building that are essential for conducting cooling load calculations. Cooling load calculation is a crucial step in designing an effective and efficient air conditioning or HVAC system for the building.

In the cooling load analysis of the airport, the detailed building geometry should be considered. Therefore, this research uses an airport geometry sketched using SketchUp software attained from previous research, including the weather data, to simulate Malaysia's climatic conditions[18]. The airport has the following dimensions:

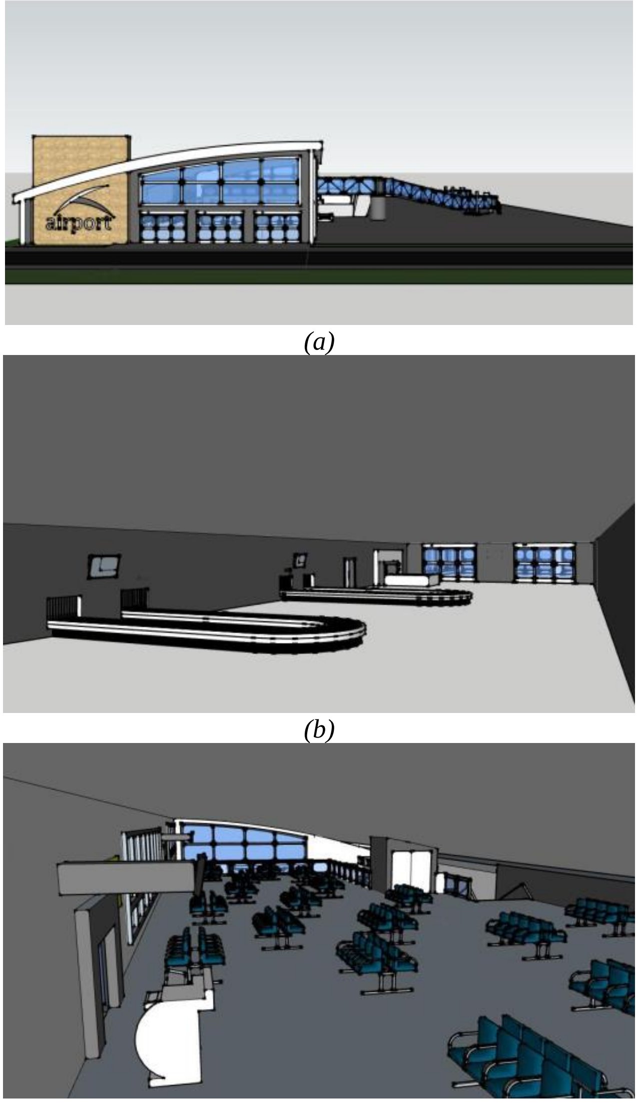
- 63 m × 24 m = 1,512 m^2
- Ceiling height = 7m (Zone A); 3m (Zone B)
- Pitch roof = 15°

The airport consists of two floors: the ground floor is the luggage room, as illustrated in Fig. 1, and the upper floor is the Airport lounge. This airport is classified as a Class III facility according to Ministerial Regulation 40 of 2016, where small passenger services could cover less than 1,000,000 people per year. There are two lines connecting the airport to the aircraft. Airport walls are made of regular concrete, using a mechanical ventilation system to provide fresh air circulation and remove stale air from indoor spaces. The area of the airport is 1,512 m^2 with a ceiling height of 7 m and 585 m^2 with a ceiling height of 3 m for the 1st and 2nd floors, respectively.

Furthermore, to ensure proper ventilation and maintain indoor air quality, a total of 13 m^3/h of fresh air per person is supplied to each zone, with an infiltration rate of 0.2 air changes per hour and fluorescent lighting at 20 W/m^2. The design indoor temperature is set at 24°C, and the relative humidity is maintained at 50%, in accordance with the ASHRAE Standard 55[19]. Various equipment will be utilized, including notebooks, desktops, and monitors. The estimated occupancy for the baggage area is 80

Table 1. Description of building geometry

		Outer Wall Length (m)	**Window Area Outer Wall (m)**	**Inner Wall Length (m)**
1st floor	North	24	48	0
	East	63	141	45
	South	24	66	13
	West	63	0	0
2nd floor	North	13	0	0
	East	45	0	0
	South	0	0	13
	West	0	12	45



(a)

(b)

(c)

Fig. 1. Airport sketch design; (a) front view of airport;(b) airport baggage area; (c) airport lounge

people, and the waiting lounge is 176 people. Sensible heat and latent heat generated by occupants are calculated as 76 W/person and 74 W/person, respectively. The area is anticipated to be active 24 hours a day, with equipment, lighting, and occupants present from 04:00 to 23:00.

2.2 *Cooling Load Analysis*

A cooling load analysis is utilized to determine the cooling capacity required in a building. It is a critical aspect of HVAC design and is performed to accurately measure the cooling equipment needed, such as an AC or chiller, for a specific building or room[20]. The main purpose of cooling load analysis is to ensure that the cooling system has an appropriate size to handle the heating and heat loss within the building, which are caused by various factors, including external factors like solar radiation, outdoor temperature, humidity, and wind, affecting heat transfer through walls, windows, and roofs[21]. Additionally, internal factors encompass the heat generated by occupants, lighting, electrical equipment, and devices within the building. Cooling load analysis considers various parameters, such as building orientation, insulation levels, occupancy schedules, lighting, and other thermal properties.

Cooling load calculation method which is used in this research is the Cooling Load Temperature Difference/Cooling Load Factor (CLTD/CLF) principle. All parameters as described earlier are used and analyzed with Panasonic Heat Load software. Each equipment, number of people, human activities, and lighting are inputted for each hour to obtain the proper cooling capacity. An oversized air conditioning system will make people discomfort and it will have a significant impact on energy consumption and costs. The selection of cooling capacity will be determined by taking the largest cooling load. The proper selection of cooling load capacity will ultimately result in reduced energy consumption and CO_2 emissions produced in the building.

2.3 *Ducting Calculation*

Duct calculation is a crucial process in HVAC system design. Its purpose is to determine the correct size and shape of ductwork to ensure efficient airflow that meets the requirements of the room or building. The duct system is highly complex in terms of its layout within a building, with varying terminal flow rate requirements from room to room and from time to time in each room [22]. A poorly designed air duct system will result in wasted energy and/or excessive installation of ductwork materials. When designing an air duct system, designers typically begin with the layout of the duct system and the airflow rate.

Several factors are considered in duct calculation, including the required volume of airflow for achieving thermal comfort, the desired air pressure, and the friction resistance of duct material and fittings. Accurate and precise calculations ensure even air distribution, minimize energy losses and reduce noise and vibrations that may occur within the system. HVAC professionals utilize computer software and industry standards like SMACNA (Sheet Metal and Air Conditioning Contractors' National Association) guidelines to perform accurate calculations for achieving optimal duct system performance.

Each zone in the airport utilizes fans equipped with the mixing box terminal with a total fan static of 0.5 in wg, 50% fan efficiency, and a supply temperature of 35°C, referring to ASHRAE Standards 62.1 and 62.2 to satisfy minimum ventilation rates.

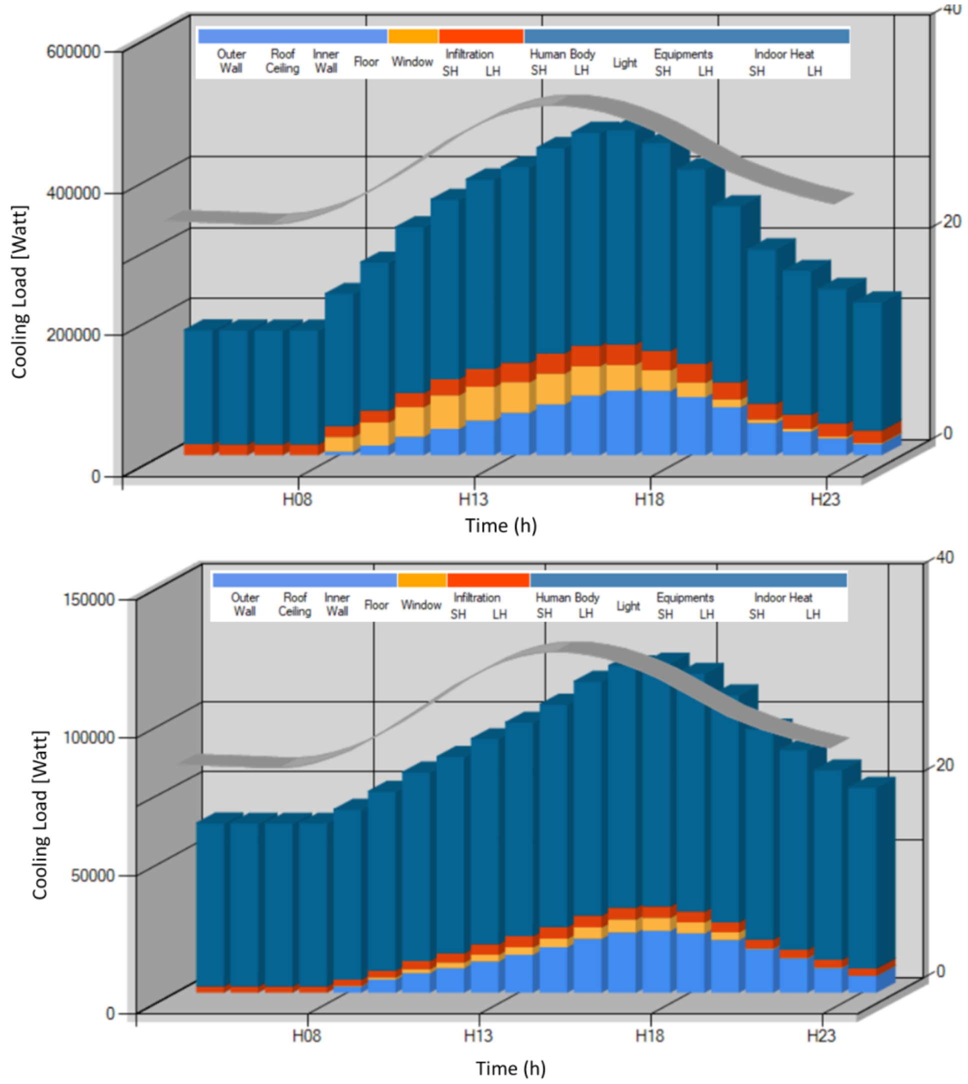


Fig. 3. Zone cooling load; airport lounge (top); airport baggage area (bottom)

The incoming air flow is determined from the ASHRAE Standard Room Total Heat (RTH) applied psychrometric, as shown in equation (1).

$$RTH = 1.19 \text{ x } L/S_{SA} \text{ x } (h_{RM} - h_{SA}) \tag{1}$$

Where L/S_{SA} represents the total incoming air quantity, h_{RM} and h_{SA} indicate the enthalpy of room air and the enthalpy of supply air, respectively. After obtaining the total air quantity in the central duct, the process proceeds to duct sizing. Duct sizing begins with calculating the duct area based on the total air quantity and initial velocity, following the parameters outlined in the SMACNA standard. Subsequently, using the equal friction method, the dimensions of the duct can be determined. From this, the total length of the required duct and the duct pressure loss, including various duct fittings and straight duct sections, can be derived.

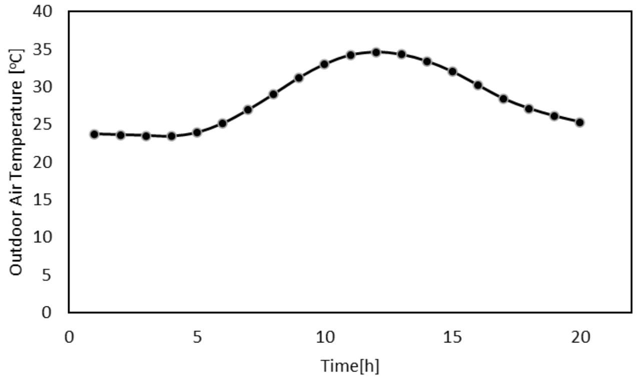


Fig. 2. Outdoor air temperature of the airport

3. Results and Discussion

3.1 Cooling Load Analysis

Based on the simulation results, the peak demand for cooling in both the Airport Lounge and Luggage Room zones is observed at 4:00 PM. Specifically, the cooling load reaches its highest levels during this time frame, as depicted in Fig. 2. The numerical values for this cooling load are 263,591 Watts for the Airport

Table 2. Airport lounge heat load

Time [h]	Outer	Roof	Inner	Floor [W]	Window [W]	Infiltration		Indoor Heat		Fresh	Total [W]
	Wall [W]	Ceiling [W]	Wall [W]			SH [W]	LH [W]	SH [W]	LH [W]	Air [W]	
H04	0	0	0	7,716	0	0	14,992	63,742	28,016	15,984	107,742
H05	0	0	0	7,716	0	0	14,816	63,742	27,840	15,718	107,300
H06	0	0	0	7,716	0	0	14,816	63,742	27,840	15,642	107,224
H07	0	0	0	7,716	0	0	14,816	63,742	27,840	15,567	107,149
H08	4,962	0	0	7,716	20,523	0	15,169	89,228	28,193	16,325	133,746
H09	13,004	0	468	7,716	32,484	768	16,050	110,466	29,074	18,186	157,726
H10	24,490	0	1,234	7,716	42,307	2,026	17,637	133,799	30,661	21,261	185,721
H11	34,610	0	2,128	7,716	47,878	3,493	19,048	151,851	32,072	24,371	208,294
H12	42,251	3,263	3,064	7,716	47,522	5,030	20,282	164,872	33,306	27,366	225,544
H13	46,217	9,287	3,829	7,716	43,424	6,287	20,987	172,786	34,011	29,488	236,285
H14	50,570	16,565	4,340	7,716	43,692	7,125	21,340	186,035	34,364	30,775	251,174
H15	54,850	24,597	4,510	7,716	41,668	7,405	21,340	196,773	34,364	31,077	262,214
H16	54,115	32,378	4,382	7,716	36,564	7,195	21,340	198,376	34,364	30,851	263,591
H17	48,359	37,900	3,999	7,716	29,160	6,566	21,164	189,726	34,188	29,981	253,895
H18	38,164	40,410	3,404	7,716	20,416	5,588	20,635	171,724	33,659	28,352	233,735
H19	24,954	39,908	2,638	7,716	11,038	4,331	19,753	146,611	32,777	26,039	205,427
H20	7,200	35,892	1,873	7,716	5,386	3,074	18,695	117,167	31,719	23,536	172,422
H21	2,322	29,617	1,319	7,716	3,794	2,165	17,637	102,960	30,661	21,412	155,033
H22	0	22,338	893	7,716	2,570	1,467	16,932	91,011	29,956	19,894	140,861
H23	0	15,060	553	7,716	1,591	908	16,403	81,854	29,427	18,718	129,999

Lounge and 82,202 Watts for the Luggage Room. These values indicate the amount of energy required to cool down each zone effectively.

The increase in the cooling load can be attributed to two types of heat: sensible heat and latent heat. During the mentioned time, the Airport Lounge experiences a sensible heat load of 198,376 Watts and a latent heat load of 24,364 Watts. Similarly, the Luggage Room has a sensible heat load of 51,523 Watts and a latent heat load of 9,105 Watts. From the cooling load calculation using Panasonic software, the total human body, lighting, and equipment loads for the sensible heat category in Airport Lounge are 13.376 Watts, 35.078 Watts, and 7.572 Watts, respectively. Furthermore, the latent load of the human body category has a load of 13.024 Watts. The heat load for the three categories has a static value over time.

In contrast to the building envelope, which includes the outer wall, roof ceiling, inner wall, floor, and windows, the heat load varies according to changes in climatic conditions at certain times. Details of the heat load for each load variation at the Airport Lounge are summarized in Table 2. Furthermore, for the baggage area, the sensible heat load generated for the human body, lighting, and equipment categories are 6,080 Watts, 13,572 Watts, and 1,328 Watts, respectively. The latent heat load produced by the human body through the release of water vapor has a value of 5,920 Watts. The details of the heat load value for each category in the baggage area are summarized in Table 3.

Several factors contribute to this intensified heat load at 4:00 PM. Firstly, the outdoor temperature plays a significant role. As the outdoor temperature rises, it results in a more significant temperature differential between the interior and exterior of the building, causing more heat to enter the building—secondly, the orientation of the building matters. The way the building is positioned affects how much solar radiation it receives. In this case, the building receives the maximum amount of solar radiation at 4:00 PM due to its specific orientation, as described in Fig. 3.

These figures also describe how the different colors and elements in the graph represent various heat sources within a space. The blue bar, for instance, encompasses heat generated by humans, equipment, and indoor activities. The red graph accounts for the heat introduced through infiltration, which is the unintended flow of outside air into the controlled indoor environment. The yellow line signifies the heat transmitted through windows, which can influence factors like sunlight and outdoor temperature. Finally, the purple bar chart provides load stemming from the building's structural components, such as walls, roofs, and floors.

In general, the proportion of different heat loads, including sensible heat, latent heat, and fresh air load,

Table 3. Airport baggage area heat load

Time [h]	Outer Wall [W]	Roof Ceiling [W]	Inner Wall [W]	Floor [W]	Window [W]	Infiltration		Indoor Heat		Fresh Air	Total [W]
						SH [W]	LH [W]	SH [W]	LH [W]		
H04	0	0	0	2,985	0	0	2,237	23,965	8,157	11,178	43,300
H05	0	0	0	2,985	0	0	2,211	23,965	8,131	10,992	43,088
H06	0	0	0	2,985	0	0	2,211	23,965	8,131	10,939	43,035
H07	0	0	0	2,985	0	0	2,211	23,965	8,131	10,886	42,982
H08	2,181	0	0	2,985	251	0	2,264	26,397	8,184	11,416	45,997
H09	4,462	0	180	2,985	829	115	2,395	29,552	8,315	12,717	50,584
H10	6,590	0	476	2,985	1,450	302	2,632	32,783	8,552	14,867	56,202
H11	8,084	0	821	2,985	2,008	521	2,843	35,399	8,763	17,043	61,205
H12	8,804	1,262	1,182	2,985	2,481	751	3,027	38,446	8,947	19,138	66,531
H13	8,582	3,593	1,477	2,985	2,760	938	3,132	41,315	9,052	20,621	70,988
H14	8,358	6,409	1,674	2,985	3,059	1,063	3,185	44,529	9,105	21,522	75,156
H15	8,226	9,517	1,740	2,985	4,132	1,105	3,185	48,685	9,105	21,733	79,523
H16	7,445	12,527	1,691	2,985	4,821	1,074	3,185	51,523	9,105	21,574	82,202
H17	6,143	14,664	1,543	2,985	4,699	980	3,158	51,994	9,078	20,966	82,038
H18	4,478	15,635	1,313	2,985	4,000	834	3,079	50,225	8,999	19,827	79,051
H19	2,551	15,440	1,017	2,985	2,832	646	2,948	46,452	8,868	18,210	73,530
H20	1,146	13,887	722	2,985	262	459	2,790	40,441	8,710	16,459	65,610
H21	416	11,459	509	2,985	185	323	2,632	36,857	8,552	14,973	60,382
H22	0	8,643	344	2,985	125	219	2,527	33,296	8,447	13,912	55,655
H23	0	5,827	214	2,985	78	136	2,448	30,219	8,368	13,089	51,676

were summarized and presented in Fig. 4. Analyzing these graphs reveals that the primary source of heat load, exceeding 70% during peak periods, originates from sensible heat. This sensible load is attributed to various factors such as lighting, windows, walls, ceiling, infiltration-related sensible heat, and equipment that emits sensible heat.

Additionally, the latent load from the human body, infiltration latent heat, and latent heat from equipment constitute over 20% of the total load during its peak. Moreover, the contribution of fresh air load is relatively the smallest compared to the other loads, comprising more than 13%. The term "fresh air load" pertains to the quantity of outdoor air required to be introduced into an indoor space. This practice aims to ensure optimal indoor air quality and facilitate adequate ventilation. In summary, the graphical representation in Figure 4 provides a comprehensive overview of the distribution of heat loads, where sensible heat is the dominant factor, followed by latent heat and fresh air load. This breakdown underscores the significance of managing these load components to maintain a comfortable and healthy indoor environment.

In summary, the simulation results reveal that the highest cooling load demands occur at 4:00 PM in both the Airport Lounge and Luggage Room zones. This heightened demand is attributed to increased sensible and latent heat levels during this time, influenced by outdoor temperature and building orientation factors.

3.2 *Duct Sizing*

The specific dry bulb temperature and relative humidity values are determined in accordance with established standards provided in different manual books. The air conditioning system is designed to deliver air within a temperature range of 10-15°C to ensure thermal comfort, with 12.8°C being the typical choice [23]. Based on this, the calculated airflow parameter from equation (1) is determined to be 13,772 CFM. This information is likely part of an HVAC or air conditioning system design, where precise temperature and airflow values are crucial for maintaining comfortable indoor conditions.

After calculating the total air volume required as 13,772 cubic feet per minute (CFM) to supply air to both zone A and zone B, the next step involves utilizing the subsequent equation to determine the appropriate duct sizes. Afterward, the work was referred to the CIBSE (Chartered Institution of Building Services Engineer) Guide B - HVAC & Refrigeration 2005 / Section 3.10 Ductwork for ducting calculation. This comprehensive guide provides insights into various facets of ductwork design, encompassing aspects such as sizing, arrangement, material selection, building types, and airflow characteristics. Additionally, it likely includes recommendations regarding the optimal maximum duct velocities to ensure the effectiveness and

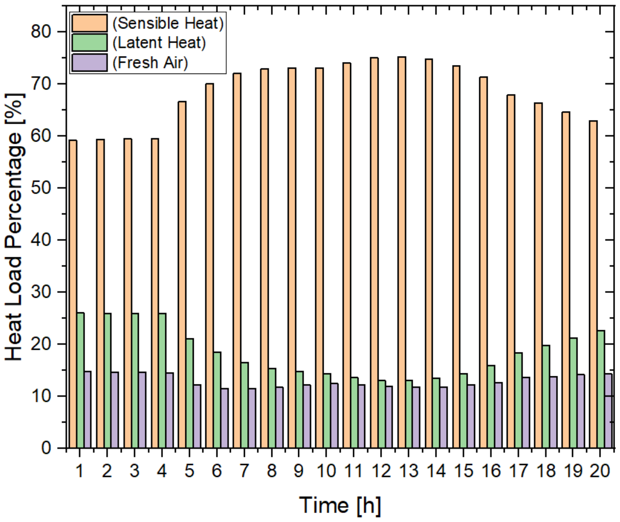


Fig. 4. The proportion of different heat loads

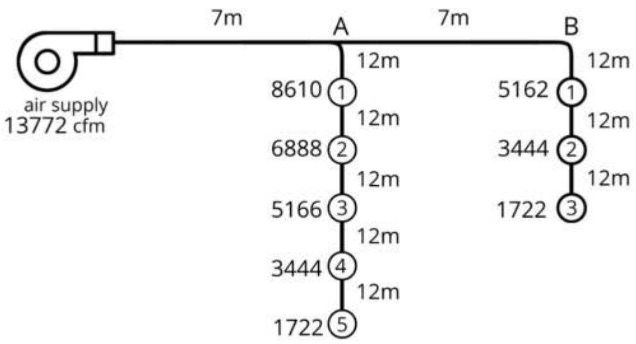


Fig. 5. Airport ducting layout

Table 4. Duct dimension

Duct Section	Air Quantity (cfm)	CFM Capacity (%)
To A	13772	100
A to 1	8610	63
1 to 2	6888	50
2 to 3	5166	38
3 to 4	3444	25
4 to 5	1722	13
Duct Area (%)	**Area (sq. ft)**	**Duct Size (in.)**
To A	4.6	26 x 22
A to 1	2.87	24 x 18
1 to 2	2.3	26 x 14
2 to 3	1.72	22 x 12
3 to 4	1.15	24 x 8
4 to 5	0.57	16 x 6

efficiency of ventilation and air distribution within buildings.

After obtaining the airflow rate and air velocity, the equivalent friction method is employed for selecting duct sizes, with reference to the SMACNA HVAC Duct Construction Standard for guidance on duct dimensions. The utilization of equivalent friction tables streamlines the process of choosing appropriate duct sizes based on the desired airflow rate and allowable pressure drop. These tables encompass a spectrum of duct sizes and corresponding equivalent lengths for various components, including elbows, tees, and transitions. Equation (2) is applied to determine the dimensions of the main duct. The outcome of this calculation reveals that the dimensions of the main duct amount to 4.6 sq.ft., with a specific duct size of 26 x 22 in.

$$Duct\ Area = \frac{Total\ Air\ Flow\ Rates\ Quantity}{Supply\ Main\ Duct\ velocity} \qquad (2)$$

Subsequently, a detailed analysis is conducted for each duct section, considering the duct area and size. This comprehensive assessment covers the entire designated area, ensuring that every aspect of the space is considered. As a result of this meticulous examination, the optimal duct sizing is determined for each specific zone within the Airport environment.

The outcomes of these calculations are summarized in Table 4 to consolidate and present the findings effectively. This tabulated representation offers a concise overview of each distinct zone's derived duct sizing information. Furthermore, the visual depiction of the results is illustrated in Fig. 5, providing a graphical representation that aids in understanding the spatial distribution and variations in duct sizing across different areas of the Airport.

This process of calculating and summarizing the duct sizing information for various zones within the Airport contributes to the overall design and optimization of the HVAC system. By individually evaluating each duct section, accounting for both area and size and subsequently consolidating these results, designers can ensure an efficient and effective air distribution system that caters to the specific requirements and characteristics of different zones within the Airport facility.

4. Conclusions

Analyzing and evaluating thermal-cooling loads using Panasonic software demonstrates its efficacy in optimizing HVAC system design for airport buildings in Indonesia's tropical climate. The study emphasizes the importance of energy-efficient cooling strategies to ensure passenger comfort and operational efficiency. By incorporating advanced simulation tools and considering real-world case studies, this research provides valuable insights for enhancing thermal management practices in airport facilities.

The findings contribute to sustainable building practices by facilitating energy-efficient cooling strategies tailored to tropical climates. Future research directions involve integrating real-time data analytics and smart control systems to enhance further the efficiency and adaptability of HVAC systems in airport buildings.

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