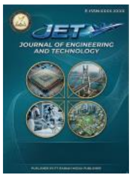

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COOLING SYSTEM CAPACITY ASSESSMENT IN EXECUTIVE-CLASS PASSENGER CARRIAGES: A STUDY OF THE ARGO PARAHYANGAN TRAIN

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Abstrak: Perkeretaapian merupakan tulang punggung transportasi massal yang menawarkan kapasitas penumpang tinggi dengan biaya yang relatif terjangkau. Salah satu permasalahan teknis yang umum terjadi adalah ketidaksesuaian antara kapasitas pendinginan terpasang dengan beban termal aktual di dalam gerbong, yang dapat memengaruhi tingkat kenyamanan. Penelitian ini bertujuan untuk mengevaluasi apakah sistem pendingin pada gerbong eksekutif kereta Argo Parahyangan telah sesuai dengan kondisi operasional nyata. Data suhu dan kelembapan relatif dikumpulkan selama tujuh hari berturut-turut dan dianalisis menggunakan metode ASHRAE. Beban pendinginan dihitung berdasarkan beberapa komponen, yaitu perpindahan panas melalui struktur, radiasi matahari, panas dari penumpang, pencahayaan, ventilasi, infiltrasi, serta faktor keamanan. Hasil penelitian menunjukkan bahwa beban pendinginan desain berkisar antara 14.899,86 W hingga 21.578,74 W, sedangkan kapasitas terpasang sebesar 34.890 W. Beban pendinginan aktual mencapai 24.445,8 W, sehingga terdapat kelebihan kapasitas sebesar 42,7%. Meskipun demikian, kondisi dalam ruangan tetap berada dalam rentang kenyamanan termal.

Kata Kunci: Beban Pendinginan, Gerbong Eksekutif, Kapasitas Pendinginan.

***Abstract:** Railways serve as a backbone of mass transportation, offering high passenger capacity at relatively affordable costs. In executive-class carriages, the performance of the air conditioning system plays a crucial role in ensuring passenger thermal comfort. This study evaluates whether the cooling system installed in the executive car of the Argo Parahyangan train is properly sized for real operating conditions. Temperature and relative humidity data were collected over seven consecutive days and analyzed using the ASHRAE method. The cooling load was calculated based on several components, including heat transfer through structural elements, solar radiation, occupant heat, lighting, ventilation, infiltration, and a safety margin. The results indicate that the design cooling load ranges from 14,899.86 W to 21,578.74 W, while the installed capacity is 34,890 W. The actual cooling load reaches 24,445.8 W, resulting in excess capacity of 42.7%. However, indoor conditions remain within the thermal comfort range.*

***Keywords:** Cooling Load; Executive Carriage; Cooling Capacity; Thermal Comfort*

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INTRODUCTION

Transportation infrastructure is one of the foundational pillars of modern society. The availability of reliable, efficient, and comfortable mobility services directly shapes the quality of life of urban and rural populations while simultaneously driving regional economic development. Among the various land transport options, railways hold a strategically important position: they are capable of moving large numbers of passengers in a single journey with a per-passenger energy footprint that is considerably lower than that of private automobiles or long-distance buses. This inherent advantage positions rail as a preferred backbone of medium- to long-distance surface transportation in many countries, including Indonesia.

Over the past two decades, Indonesia's rail sector has undergone substantial modernisation. PT Kereta Api Indonesia (Persero), the national rail operator, has continuously elevated its service standards in response to increasingly discerning passengers. Among the dimensions of service quality that have attracted growing attention, in-carriage comfort particularly in executive class stands out as especially critical. Executive-class travellers pay a premium fare and, accordingly, expect an environment that goes beyond adequate seating. They demand spacious accommo dations, reliable on-board amenities, and crucially a thermal environment that remains consistently pleasant throughout the journey, regardless of external weather conditions or the number of co-passengers.

Thermal comfort is formally defined as the psychological state in which an individual expresses satisfaction with the thermal environment (ASHRAE Standard 55). It is governed by four primary environmental parameters—air temperature, relative humidity, mean radiant temperature, and air velocity—alongside two personal variables: metabolic activity level and clothing insulation (clo value). In an enclosed, mechanically conditioned space such as a railway carriage, all four environmental parameters can, in principle, be regulated simultaneously through a well-designed air conditioning (AC) system. Achieving this regulation consistently, however, requires that the AC system be correctly sized for the thermal loads it must handle.

The air conditioning challenge in railway carriages differs fundamentally from that of stationary buildings. A moving carriage is subjected to continuously varying solar angles, creating dynamic radiant heat gain profiles across its walls, roof, and glazing throughout the journey. High travel speeds generate significant conductive and convective exchanges between the carriage shell and the ambient environment.

Occupancy levels fluctuate at every stop, causing abrupt changes in internal metabolic load. Furthermore, the physical constraints of carriage design impose strict limits on the size and weight of mechanical equipment. These factors collectively make the engineering of a railway carriage AC system a more complex undertaking than conventional building HVAC design, requiring careful analysis of both peak and part-load conditions.

The Argo Parahyangan is among the premier executive-class rail services in Indonesia, connecting the capital Jakarta with the major city of Bandung on one of the nation's busiest passenger corridors. With multiple daily departures and consistently high ridership, the quality of thermal comfort aboard this service has tangible consequences for a large number of passengers. Complaints about excessively cold cabin temperatures, commonly reported on Indonesian executive-class trains, do not merely represent momentary discomfort—prolonged exposure to temperatures below the physiological comfort threshold can adversely affect passenger health, particularly for elderly travellers or those with circulatory conditions.

The mismatch between installed cooling capacity and actual thermal demand is a widespread technical issue in the Indonesian rail fleet. Cooling systems are conventionally sized against the worst-case peak load scenario—a fully occupied carriage under maximum solar irradiance. In everyday operations, however, this worst-case condition rarely materialises. As a result, AC units frequently run at a fraction of their rated capacity for the majority of operational hours. This over-capacity operation produces two simultaneous negative outcomes: first, unnecessary energy consumption as the system works harder than the thermal load demands; and second, cabin temperatures that fall below the ideal comfort range, especially when the carriage is lightly occupied—a condition widely reported by passengers as a key source of dissatisfaction.

A thorough understanding of the actual cooling load of a railway carriage is therefore the essential prerequisite for both designing and retrospectively evaluating an efficient AC system. The total cooling load comprises several interacting components. External loads arise from heat conduction through the structural envelope—walls, roof, floor, and windows—driven by the temperature differential between the conditioned interior and the hot exterior. Solar radiation transmitted directly through the glazed surfaces adds a further, orientation-dependent radiant component. Internal loads originate from passenger metabolism, heat dissipated by electrical equipment such as lighting and electronic displays, and the fan heat gain associated with air distribution. Beyond these, fresh-air ventilation introduces an intentional outdoor-air load, while infiltration adds an uncontrolled component through gaps in the carriage structure.

Each of these load components exhibits a distinct dynamic character. Conduction and radiation loads shift continuously with solar position, carriage orientation, and local weather along the route. Occupant loads fluctuate with boarding and alighting at each station. Lighting loads remain relatively steady during service hours but may vary between daytime and night operations. Capturing this variability accurately is indispensable for determining the most technically appropriate and economically rational cooling capacity for a given carriage type.

The standard analytical framework for quantifying these loads—both sensible (associated with dry-bulb temperature change) and latent (associated with moisture addition)—is provided by the ASHRAE Fundamental Handbook. Sensible cooling addresses the thermal component of the load, while latent cooling handles the dehumidification requirement. Both must be carefully accounted for, because an AC system's function extends beyond temperature reduction to include moisture control; elevated relative humidity at moderate temperatures is well documented as a source of discomfort even when temperature alone appears acceptable.

Prior research on air conditioning in Indonesian passenger rolling stock has highlighted persistent capacity mismatches across multiple train classes (Homzah, 2016; Hidayat & Restu, 2017; Safitri & Hantoro, 2018). Both over-capacity and under-capacity scenarios carry significant penalties: the former wastes energy and chills passengers, while the latter leaves travellers uncomfortably warm. Accurate capacity evaluation is therefore essential not only for passenger welfare but also for the long-term energy efficiency and equipment longevity of the rail fleet.

Against this background, the present study was undertaken with four specific objectives: (1) to calculate all individual cooling load components of the Argo Parahyangan executive carriage using field-measured temperature and humidity data; (2) to compare the computed total cooling load against the rated capacity of the currently installed AC system; (3) to assess the thermal comfort quality of the passenger compartment through psychrometric chart analysis; and (4) to formulate evidence-based technical recommendations for optimising AC capacity and improving energy efficiency without compromising the comfort standards expected by executive-class passengers. The findings are intended to contribute both scientific knowledge and actionable guidance for the improvement of air conditioning systems in Indonesia's executive rail fleet.

Transportation infrastructure is one of the foundational pillars of modern society. The availability of reliable, efficient, and comfortable mobility services directly shapes the quality of life of urban and rural populations while simultaneously driving regional economic development. Among the various land transport options, railways hold a strategically important position: they are capable of moving large numbers of passengers in a single journey with a per-passenger energy footprint that is considerably lower than that of private automobiles or long-distance buses. This inherent advantage positions rail as a preferred backbone of medium- to long-distance surface transportation in many countries, including Indonesia.

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METHOD

Research Design

This study adopted a quantitative analytical approach. Primary data consisting of indoor and outdoor air temperature and relative humidity were gathered through direct on-site measurement over seven consecutive days of regular train service. The measurements were subsequently processed using standard cooling load calculation procedures referenced to the ASHRAE Fundamental Handbook (1997). The unit under investigation was a single executive-class passenger carriage of the Argo Parahyangan intercity train, equipped with a package-type air conditioning system using R-22 refrigerant.

Cooling Load Components

The total cooling load was resolved into seven primary components: (1) conductive heat gain through the structural envelope comprising walls, roof, floor, and glazing; (2) solar radiation transmitted through window glass; (3) occupant metabolic heat in both its sensible and latent fractions; (4) heat dissipated by fluorescent lighting; (5) infiltration of unconditioned outdoor air through structural gaps; (6) intentional fresh-air ventilation; and (7) a 5% safety allowance applied to the aggregate load. The air distribution system operates on an induction principle in which supply air passes through the cooling coil before being delivered to the passenger compartment. The fan heat gain factor was set at 7% of the room sensible load, and duct leakage losses were assumed at 20% of total supply air volume.

Governing Equations

Conductive heat transfer through each structural component was computed using the overall heat transfer coefficient relationship:

$$Q = U \cdot A \cdot \Delta t \quad \ldots\ldots \quad (1)$$

where Q is the heat transfer rate (W), U is the overall thermal transmittance coefficient (W/m²·K), A is the surface area (m²), and Δt is the temperature difference between the outer and inner surface conditions (K).

Solar heat gain through opaque components such as the roof and walls was evaluated using the equivalent temperature differential method:

$$\Delta te = 0.78(Rs/Rm)\cdot\Delta tem + [1 - 0.78(Rs/Rm)]\cdot\Delta te \tag{2}$$

where Rs denotes the actual solar irradiance and Rm represents the maximum solar irradiance under design conditions. For glazed surfaces, solar heat transmission was determined by:

$$Q = \text{Peak Load} \times \text{Area} \times \text{Shade Factor} \times \text{Shash Factor} \times \text{Storage Factor} \tag{3}$$

Passenger heat gains were estimated assuming a sedentary activity level at a mean radiant temperature of 57.5 °C, yielding a latent heat output of 235 Btu/hr and a sensible heat output of 215 Btu/hr per person:

$$Ql = ql \times n \tag{4}$$

$$Qs = qs \times n \times CLF \tag{5}$$

where n is the number of occupants and CLF is the cooling load factor accounting for thermal storage in the carriage structure. The heat gain attributable to fluorescent lighting was calculated as:

$$Q = \text{Total Lighting Power (W)} \times 1.25 \times 0.996 \tag{6}$$

Sensible and latent loads arising from ventilation and infiltration airflows were determined using:

$$Qs = 1.08 \times CFM \times \Delta T \tag{7}$$

$$Ql = 0.68 \times CFM \times (w_0 - w) \tag{8}$$

The outdoor air ventilation rate was set at 15 CFM per occupant in accordance with standard office-space ventilation guidelines, which represents an accepted benchmark for enclosed passenger transport environments.

Table 1. Technical Specifications of the Installed AC Unit and Carriage

Technical Parameter	Specification
System Type	Cooling Only
Unit Model	T.6014.V
Total Installed Cooling Capacity	34,890 W
Compressor Type	Fully Hermetic — 2 units
Compressor Power Input	2 × 3.1 kW at 380 V
Refrigerant	R-22 (Thermostatic Expansion Valve)
Condenser Capacity	15,000 kcal/hr
Carriage Body Length	14,135 mm
Carriage Width	2,642 mm
Maximum Operating Speed	130 km/h

RESULTS AND DISCUSSION

Heat Gain Through the Structural Envelope

Conduction and radiation loads were computed for each structural element based on seven days of temperature measurements. The roof, by virtue of its horizontal orientation and unobstructed exposure to the sky, recorded the highest individual component average of 79.13 W. The south- and north-facing walls, which receive more diffuse and evenly distributed solar exposure throughout the day, each contributed an average of 72.33 W. The east-facing wall yielded 71.01 W, while the west-facing wall—subjected to lower-angle afternoon sun—produced a comparatively lower average of 52.45 W. Collectively, the mean weekly heat gain through the roof and all wall surfaces was 336.32 W.

The glazed surfaces displayed orientation-dependent patterns consistent with the solar geometry at Indonesia's near-equatorial latitude. West-facing glass registered the highest average solar load at 72.63 W, reflecting the intensity of late-afternoon irradiance. The combined south and north glazing contributed 38.00 W, while east-facing glass produced the lowest glazing load of 15.38 W. This directional asymmetry underscores the importance of specifying glazing properties and shading devices that are responsive to the carriage's prevailing solar exposure profile.

Table 2. Mean Weekly Heat Gain Through Structural Components

Component	Orientation / Position	Mean Heat Gain (W)
Roof	Horizontal (top)	79.13
Wall	South & North	72.33
Wall	West	52.45
Wall	East	71.01
Subtotal — Roof & Walls	—	336.32
Glazing	East	15.38
Glazing	South & North	38.00
Glazing	West	72.63

Occupant and Lighting Heat Gains

The occupant heat gain component exhibited the widest variability among all load sources, reflecting the direct dependence of this contribution on carriage seat occupancy. At maximum capacity, the sensible occupant load reached 3,150.5 W—approximately five times the minimum recorded value of 630.1 W observed at low ridership. The latent fraction, which represents moisture released through respiration and perspiration, ranged from 688.7 W at minimum occupancy to 3,443.5 W when fully occupied. This five-fold variation between peak and minimum conditions underscores a critical design consideration: sizing a system exclusively for worst-case peak occupancy will inevitably produce over-cooling whenever the carriage is less than fully loaded, which is the prevailing condition for most service hours.

Fluorescent lighting constituted the single largest and most consistent internal load component at a fixed value of 9,220 W. Fluorescent lamps convert only a fraction of their electrical input into visible light, releasing the majority as heat directly into the conditioned space. This finding carries a clear implication for system optimisation: transitioning from fluorescent to LED technology—which achieves comparable luminous output at roughly 40–60% of the power consumption—could reduce the internal lighting load by an estimated 3,700–5,500 W, representing a proportional reduction in the required cooling capacity.

Table 3. Cooling Load Contributions from Occupants and Lighting

Load Source	Condition	Heat Gain (W)
Occupant Sensible Load	Minimum (low occupancy)	630.1
Occupant Sensible Load	Maximum (full occupancy)	3,150.5
Occupant Latent Load	Minimum (low occupancy)	688.7
Occupant Latent Load	Maximum (full occupancy)	3,443.5
Fluorescent Lighting	Constant (all operating hours)	9,220.0

Infiltration and Ventilation Loads

Infiltration of unconditioned outdoor air produced a mean weekly sensible load of 3,297.71 W, placing it as the second-largest external contributor after the lighting load. The corresponding latent infiltration component was negligible at 0.81 W, indicating that the humidity differential between the outdoor environment and the conditioned carriage interior was small under the measurement conditions. The substantial sensible infiltration value reflects the pronounced temperature contrast between the hot ambient air outside and the cooled cabin interior—a differential that is especially pronounced on high-irradiance days along the Jakarta–Bandung route.

The intentional ventilation load followed a closely analogous pattern, with a mean sensible component of 3,297.86 W and a latent component of 7.94 W. The near-identical sensible magnitudes of infiltration and ventilation are physically reasonable, as both processes introduce outdoor air at elevated temperature into a cooled space. Together, infiltration and ventilation account for more than 6,500 W of combined sensible load—roughly 26% of the total actual cooling load. This proportion highlights outdoor-air management as a critical lever for energy efficiency improvement. Strategies such as demand-controlled ventilation, air-to-air heat recovery, and improved carriage sealing could substantially reduce these contributions without compromising air quality.

Total Cooling Load Evaluation and Installed Capacity Assessment

Aggregating all load components across the seven-day observation period yielded a mean weekly Total Sensible Heat (TSH) of 6,058.85 W and a mean Total Latent Heat (TLH) of 2,178.2 W. The daily Grand Total Heat (GTH) was not constant across the week: the minimum daily GTH occurred on Thursday, while the peak weekly value was recorded on Friday. This day-to-day variation is attributable to the combined effects of fluctuating ridership levels and weather variability along the route—factors that cause the occupant and conduction/radiation components to shift in parallel. Comparison of the installed cooling capacity against the computed load profile reveals a substantial imbalance. The installed capacity of 34,890 W is markedly higher than the design load ceiling of 21,578.74 W and even further exceeds the mean actual operating load of 24,445.8 W. The installed capacity thus exceeds the actual demand by 10,444.2 W, equivalent to a surplus of approximately 42.7%. The gap between operational cooling capacity and actual demand, measured at 8,237.05 W, means the system runs with a very large idle reserve throughout most of its service life.

This chronic over-capacity carries multiple technical and operational penalties. From an energy efficiency standpoint, a system operating well below its rated load undergoes frequent short-cycle on–off sequences, because the thermostat is satisfied quickly and triggers shutdown before the compressor reaches thermodynamic steady state. These rapid cycling events accelerate compressor wear and increase the risk of bearing failure, reducing overall system longevity. From the passenger comfort perspe ctive, the over-capacity drives cabin temperature below the comfort zone especially during periods of low occupancy and impairs precise humidity control, because the cooling coil operates for insufficient durations to complete the dehumidification cycle optimally. Both outcomes represent avoidable costs: higher maintenance expenditure and passenger dissatisfaction (Homzah, 2016; Hidayat & Restu, 2017).

Table 4. Comprehensive Comparison of Cooling Loads and Installed Capacity

Evaluation Parameter	Value (W)	Remark
Design Cooling Load — Minimum	14,899.86	Lowest design condition
Design Cooling Load — Maximum	21,578.74	Peak design condition
Total Actual Cooling Load (measured)	24,445.80	Field measurement result
Installed Cooling Capacity	34,890.00	AC unit specification
Surplus Capacity vs. Actual Load	10,444.20 (42.7%)	Energy waste potential
Mean Weekly TSH	6,058.85	Total Sensible Heat
Mean Weekly TLH	2,178.20	Total Latent Heat
Mean Weekly GTH (operational)	8,237.05	Grand Total Heat

Psychrometric Assessment of Thermal Comfort

The thermal quality of the passenger compartment was evaluated by plotting measured air state points characterised by dry-bulb temperature, wet-bulb temperature, and relative humidity on the ASHRAE psychrometric chart. Both design-condition parameters and field-measured actual values were examined against the ASHRAE Standard 55 comfort zone boundary.

The analysis confirmed that all plotted state points, whether drawn from design assumptions or from the seven-day measurement campaign, fall within the accepted thermal comfort region. Cabin dry-bulb temperatures were maintained in the range of 24–27 °C, and relative humidity remained within 50–55%—conditions that satisfy the ASHRAE recommendation for spaces with elevated radiant heat exposure. This outcome demonstrates that the existing AC system, despite its oversizing, continues to deliver an acceptable thermal environment in quantitative terms.

However, the psychrometric analysis also reveals that this comfortable outcome is achieved at a disproportionately high energy cost. The installed capacity exceeding actual demand by 42.7% implies that compressors and ancillary components operate at sustained partial load, accumulating unnecessary electrical consumption and mechanical stress. From a sustainability and lifecycle cost perspective, rightsizing the AC system to better align with the actual load profile would allow the carriage to remain within the psychrometric comfort zone while substantially reducing energy consumption and maintenance frequency. A capacity range of 25,000–28,000 W, supplemented by a variable-capacity compressor or inverter-driven control system, is estimated to deliver equivalent or superior comfort outcomes at materially lower operational cost.

CONCLUSION

Based on the cooling load calculations and capacity assessment conducted on the executive-class passenger carriage of the Argo Parahyangan train, the following conclusions are drawn:

1. The installed cooling capacity (34,890 W) substantially exceeds both the upper bound of the design cooling load (14,899.86–21,578.74 W) and the total measured actual load (24,445.8 W). This surplus, amounting to 10,444.2 W or approximately 42.7% above actual demand, constitutes a source of avoidable energy waste and

contributes to cabin temperatures that fall below the optimal comfort range, particularly during periods of low ridership.

2. ‘The dominant cooling load component is fluorescent lighting, which contributes a constant 9,220 W—the largest single internal load. Infiltration and ventilation each add approximately 3,297 W in sensible heat. Occupant load is the most variable component, with sensible values spanning 630.1 W at minimum occupancy to 3,150.5 W at full capacity, and latent values ranging from 688.7 W to 3,443.5 W correspondingly.
3. Daily cooling load demand varied across the observation week. The Grand Total Heat reached its weekly minimum on Thursday and its peak on Friday. Mean weekly aggregates were 6,058.85 W for Total Sensible Heat and 2,178.2 W for Total Latent Heat, reflecting the combined influence of day-to-day occupancy fluctuations and weather variability.
4. Psychrometric chart analysis confirmed that the passenger compartment conditions—under both design and field-measured scenarios—fall within the ASHRAE thermal comfort zone. Cabin temperature was maintained at 24–27 °C with relative humidity at 50–55%, meeting the requirements for spaces with elevated radiant heat exposure.
5. It is recommended that the AC capacity specification for executive-class carriages be revised downward to a range of 25,000–28,000 W, complemented by a variable-capacity compressor or inverter-based control system to match output dynamically to the actual load. Additionally, replacement of fluorescent lighting with LED technology is estimated to reduce the internal thermal load by 30–40%, which would further decrease the total cooling demand and allow for a corresponding reduction in installed capacity—yielding energy savings, lower maintenance costs, and improved passenger comfort in equal measure.

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