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SCHOOL OF ENGINEERING
DEPARTMENT OF MECHANICAL ENGINEERING**

REPORT ON



Thermal Load Analysis, HVAC System Sizing, and Energy Performance Optimization of a Residential Building

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Introduction

1.1 Objective

This report presents a complete thermal design study for a residential building located in Tilottama, Rupandehi, in the Terai plains of western Nepal. The study follows the scope defined in Assignment 1 of the Refrigeration and Air Conditioning course: building characterization, heating and cooling load estimation, HVAC system selection and sizing, seasonal energy demand forecasting, and an energy efficiency improvement study. Two representative rooms of the residence the living room (Room 1) and a secondary room (Room 2) were selected for detailed analysis, as they capture the two most common envelope conditions in the house (two exterior walls with two windows, and a single exterior wall with one window).

1.2 Scope and Approach

Heating loads were computed using the steady-state UA (transmission) method at ASHRAE winter design conditions, and cooling loads were computed using the ETD/CLTD method with separate sensible and latent components at ASHRAE summer design conditions. These load calculations, completed in the accompanying calculation worksheets, form the technical basis for the HVAC equipment sizing, seasonal energy forecast, and efficiency study presented in the following sections.

2. Building Characterization

2.1 Location and Site Details

The residence is located in Tilottama Municipality, Rupandehi District, in the Terai (lowland) region of western Nepal, close to Bhairahawa. The site coordinates and climate classification are summarized below.

Parameter	Value
Location	Tilottama, Rupandehi, Nepal
Latitude / Longitude	27.574° N / 83.461° E
Elevation	118 m above mean sea level
Building orientation	South-facing (primary glazed facade)
climate classification	humid subtropical, dry winter
Surrounding shading	Open plot, no significant obstruction; south wall receives direct solar exposure through most of the year

2.2 Building Type and Layout

The building is a single detached residential house. Two rooms were selected for detailed thermal analysis, representing the two distinct envelope-exposure conditions found in the house:

Room	Function	Dimensions (L × W × H)	Floor Area	Exterior Walls
Room 1	Living Room	13 ft × 11 ft × 10 ft	143 ft ²	South (11 ft) and West (13 ft) — two exterior walls, two windows

Room	Function	Dimensions (L × W × H)	Floor Area	Exterior Walls
Room 2	Secondary Room / Bedroom	11 ft × 10 ft × 10 ft	110 ft ²	West (11 ft) only — one exterior wall, one window

Both rooms share interior partition walls with adjoining conditioned spaces and interior (non-exterior) doors on the east wall. Combined conditioned floor area analyzed in this study is 253 ft² (23.5 m²).

2.3 Envelope Construction Details

Construction details were back calculated from the resistance (R-value) build-ups used in the load calculations, corresponding to typical Nepali residential construction practice.

Element	Assumed Construction	U-value (Btu/hr·ft ² ·°F)	U-value (W/m ² ·K)
Exterior wall	225 mm (9 in) burnt-clay brick masonry, 12 mm cement plaster both faces	0.35	1.99
Roof	125 mm (5 in) uninsulated RCC flat slab, directly exposed to ambient/solar	0.75	4.26
Floor	Concrete slab-on-grade	0.32	1.82
Window (glass)	Single-pane ordinary clear glass, SHGC ≈ 0.75	0.86	4.88
Door	Solid panel door	0.39	2.21

2.4 Occupancy and Usage Pattern

- Occupancy: 5 occupants per room considered for internal heat gain and people-method ventilation sizing (residential application).
- Lighting: Fluorescent fixtures, combined wattage input of 21 W (12 W + 9 W fixtures) per room.
- Appliances (Room 1): ceiling fan (75 W) and mobile charger (15 W).
- Appliances (Room 2): ceiling fan (75 W) and television (100 W).
- Air leakage: estimated by the crack method from window and door perimeters — 20.2 CFM (Room 1) and 13.9 CFM (Room 2).
- Ventilation: sized independently per room by the people method (5 persons × 25 CFM/person = 125 CFM per room), which governed over the area method (≈27.5 CFM).

2.5 Design Conditions Summary

Parameter	Winter (Heating) Design	Summer (Cooling) Design
Outdoor dry-bulb temperature (DBT)	42.85 °F (6.0 °C)	106.76 °F (41.5 °C)
Outdoor wet-bulb temperature (WBT)	—	83.48 °F (28.6 °C)
Indoor design DBT	77 °F (25 °C)	77 °F (25 °C)
Indoor design RH	50 %	50.1 %
Design temperature difference (ΔT)	34.15 °F (19.0 °C)	29.76 °F (16.5 °C, DBT basis)
Daily temperature range (for ETD/CLTD)	—	18.97 °C (60.1 °F)

These design conditions correspond to ASHRAE-style extreme design days (near-peak, not seasonal averages) and are intentionally more severe than the typical monthly climate normals used later in the seasonal energy forecast (Section 5), consistent with standard equipment-sizing practice.

3. Heating and Cooling Load Estimation

3.1 Methodology

Two independent, complementary methods were used, matching the two design conditions in Section 2.5:

- Heating load — Steady-state UA (transmission) method: $Q = U \times A \times \Delta T$ for each envelope surface, plus infiltration and ventilation sensible loss ($Q = 1.08 \times \text{CFM} \times \Delta T$), summed and increased by a 10% safety factor.
- Cooling load — ETD/CLTD method: conduction gain uses an Equivalent Temperature Difference ($\text{ETDc} = \text{ETD} + \text{correction factor}$) in place of the simple ΔT , solar gain through glass uses $q = \text{SHGC} \times \text{solar radiation intensity} \times \text{window area}$, and internal/ventilation/infiltration gains are computed separately for sensible and latent components.

Interior partition walls and interior doors carry no heat exchange in the heating calculation (assumed equal temperature on both sides), whereas the cooling calculation applies an adjusted temperature difference across partitions to account for solar-heated adjoining spaces during the day. This is a standard modeling distinction between the two design conditions and is retained from the original calculation sheets.

3.2 Heating Load Analysis (Steady-State UA Method)

Design condition: indoor 77 °F, outdoor 42.85 °F, $\Delta T = 34.15$ °F, applied uniformly to all envelope components.

Room 1 — Living Room

Component	Heat Loss (Btu/hr)
Wall	2,486.12
Window	939.81
Door (interior)	0.00
Roof	3,662.59
Floor	1,562.70
Infiltration	744.99
Ventilation	4,610.25
Subtotal	14,006.46
Total with 10% safety factor	15,407.11 Btu/hr = 4.52 kW

Room 2 — Secondary Room

Component	Heat Loss (Btu/hr)
Wall	1,171.35
Window	352.43
Door (interior)	0.00
Roof	2,817.38
Floor	1,202.08

Component	Heat Loss (Btu/hr)
Infiltration	512.66
Ventilation	4,610.25
Subtotal	10,666.15
Total with 10% safety factor	11,732.77 Btu/hr = 3.44 kW

Heating Load Summary

Room	Btu/hr	kW	Tons (ref. only)
Room 1	15,407.11	4.52	1.28
Room 2	11,732.77	3.44	0.98
Total House (2 rooms)	27,139.88	7.95	2.26

Ventilation is the single largest heating-load component in both rooms (33% of Room 1's load, 43% of Room 2's), because 125 CFM was applied independently to each room by the people method. This assumption should be re-checked against actual code-minimum ventilation rates, since it materially inflates both the heating and cooling equipment sizing (see Section 6).

3.3 Cooling Load Analysis (ETD/CLTD Method)

Design condition: outdoor 106.76 °F DBT / 83.48 °F WBT, indoor 77 °F / 50.1% RH. Both sensible (qs) and latent (qL) components are reported; only sensible heat contributes to wall/roof/floor/glass conduction and solar gain, while people, ventilation, and infiltration contribute both.

Room 1 — Sensible Heat Gain Components

Component	Heat Gain (Btu/hr)
Glass — conduction	816.52
Glass — solar (West + South windows)	2,742.00
Wall — West	1,073.80
Wall — South	819.00
Partition walls (2)	1,744.17
Floor	1,128.89
Roof	4,933.50
Door	379.08
Lighting	99.07
People (sensible)	1,150.00
Appliances	76.73
Infiltration (sensible, 20.2 CFM)	649.24
Ventilation (sensible, 125 CFM)	4,017.60
Sensible subtotal	19,629.59
Latent Component	Heat Gain (Btu/hr)
People (latent)	600.00
Infiltration (latent)	1,043.94

Component	Heat Gain (Btu/hr)
Ventilation (latent)	6,460.00
Latent subtotal	8,103.94
Room 1 Totals	Btu/hr
Total sensible + latent (before SF)	27,733.53
Total with 10% safety factor	30,506.88 (2.54 TR)
Sensible Heat Ratio (SHR)	0.71

Room 2 — Sensible Heat Gain Components

Component	Heat Gain (Btu/hr)
Glass — conduction	307.12
Glass — solar (West window)	1,467.00
Wall — West	880.80
Partition wall (North)	953.26
Floor	871.55
Roof	3,795.00
Door	379.08
Lighting	99.07
People (sensible)	1,150.00
Appliances	366.58
Infiltration (sensible, 13.9 CFM)	446.76
Ventilation (sensible, 125 CFM)	4,017.60
Sensible subtotal	14,733.81
Latent Component	Heat Gain (Btu/hr)
People (latent)	600.00
Infiltration (latent)	718.35
Ventilation (latent)	6,460.00
Latent subtotal	7,778.35
Room 2 Totals	Btu/hr
Total sensible + latent (before SF)	22,512.16
Total with 10% safety factor	24,763.38 (2.06 TR)
Sensible Heat Ratio (SHR)	0.65

3.4 Combined Load Summary

Room	Sensible (Btu/hr)	Latent (Btu/hr)	Total (Btu/hr)	With 10% SF (Btu/hr)	Tons (TR)
Room 1	19,629.59	8,103.94	27,733.53	30,506.88	2.54
Room 2	14,733.81	7,778.35	22,512.16	24,763.38	2.06
Total House	34,363.40	15,882.29	50,245.69	55,270.26	4.61

4. HVAC System Selection and Sizing

4.1 System Type Selection and Justification

Both a winter heating requirement (up to 4.52 kW) and a larger summer cooling requirement (up to 30,506 Btu/hr / 2.54 TR) exist for this residence. Rather than installing separate heating and cooling appliances, a reversible air-to-air inverter heat pump split system is recommended for each room:

- Dual-function — a single outdoor condensing unit and indoor evaporator unit provide both cooling (summer) and heating (winter) by reversing the refrigerant cycle, avoiding the cost and space of separate electric heaters.
- Inverter (variable-speed) compressor — modulates capacity to match part-load conditions across the year rather than short-cycling, improving comfort and seasonal efficiency (relevant given the wide swing between design load and average seasonal load shown in Section 5).
- Moderate winter design DBT (6.0 °C) — well within the efficient operating range of an air-source heat pump (typical heating COP 2.5–3.5 at outdoor temperatures above 0 °C), so heat-pump heating is more economical than resistive electric heating.
- Zoned (room-wise) control — Room 1's load (2.54 TR cooling / 4.52 kW heating) is materially larger than Room 2's (2.06 TR / 3.44 kW); independent per-room units avoid overcooling/overheating one room to satisfy the other.
- R32 refrigerant — current-generation residential split systems in Nepal predominantly use R32, which has a lower global warming potential than the legacy R410A/R22 refrigerants and is compatible with inverter rotary/scroll compressors.

4.2 Required Capacity per Room

Room	Cooling Requirement	Heating Requirement	Governing Load
Room 1	30,506.88 Btu/hr (2.54 TR)	15,407.11 Btu/hr (1.28 TR eq.)	Cooling
Room 2	24,763.38 Btu/hr (2.06 TR)	11,732.77 Btu/hr (0.98 TR eq.)	Cooling

Equipment must always be rounded up to the next standard manufactured capacity, never down, so that the peak design-day condition is met with margin — consistent with the sizing approach used for the heating-only equipment in the companion heating load study.

4.3 Manufacturer Catalogue-Based Equipment Selection

Standard residential split systems are manufactured in discrete nominal capacities (1.0, 1.5, 2.0, 2.5, 3.0 TR). Applying the round-up rule to the Section 4.2 requirements gives the following selections, referenced against a currently available inverter heat-pump split line (Hitachi DC Inverter series, R32 refrigerant) sold in the Nepal market:

Room	Required Capacity	Selected Nominal Capacity	Indicative Model Class	Refrigerant	Efficiency (ISEER, ex. 2 TR unit)
Room 1	2.54 TR	3.0 TR (36,000 Btu/hr)	Wall-mount DC inverter heat-pump split	R32	≈ 4.5–5.0
Room 2	2.06 TR	2.5 TR (30,000 Btu/hr)	Wall-mount DC inverter heat-pump split	R32	≈ 4.5–5.0

Indicative reference specifications (2.0 TR class unit, same product family) list a 100% copper condenser coil, multi-speed inverter rotary compressor, and rated Indian Seasonal Energy Efficiency Ratio (ISEER) of approximately 5.0 for the 5-star tier [see References]. Equivalent capacity heat-pump models are also available from Daikin and LG in the Nepal market and may be substituted subject to a like-for-like ISEER/COP comparison at the time of procurement.

- Compressor type: variable-speed (inverter) rotary compressor.
- Condenser: air-cooled, wall/ground-mounted outdoor unit with 100% copper coil.
- Evaporator: wall-mounted indoor unit, one per room, matched to the outdoor unit.
- Expansion device: electronic expansion valve (EEV), standard on inverter systems for precise refrigerant metering across the modulating capacity range.
- Defrost: automatic reverse-cycle defrost during winter heating operation (standard on heat-pump splits) — relevant since outdoor coil frosting can occur at the 6 °C design condition.

4.4 System Schematic Layout

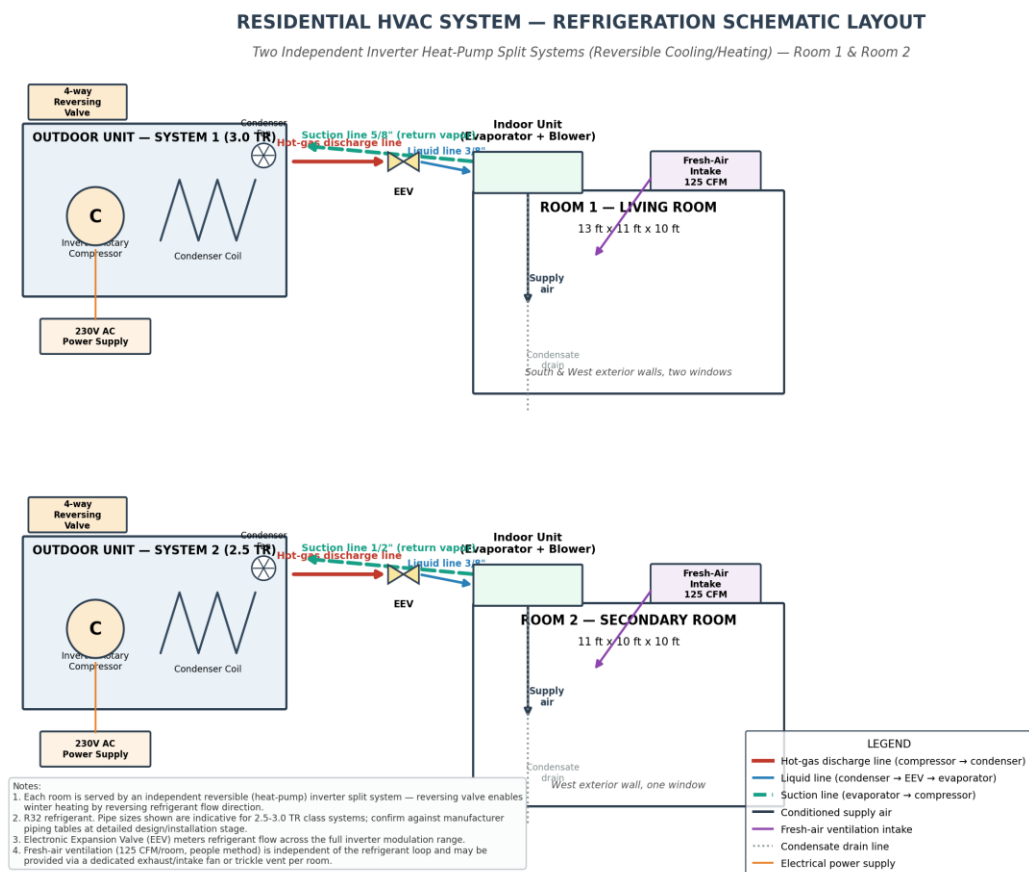


Figure 4.1 — Schematic layout of the two-zone inverter heat-pump split system, showing outdoor unit(s), refrigerant piping to each indoor unit, conditioned supply air to each room, and independent fresh-air ventilation intake sized by the people method.

5. Seasonal Energy Demand Forecasting

5.1 Climate Overview

Tilottama/Bhairahawa has a Cwa (humid subtropical, dry-winter) climate with an annual mean temperature of about 24.2 °C. Summers (April–June) are hot with peak highs exceeding 40 °C shortly before monsoon onset; the monsoon (June–September) is hot and humid; winters (December–February) are mild, rarely falling below 5–8 °C. Estimated monthly climate normals used for the seasonal forecast are shown below.

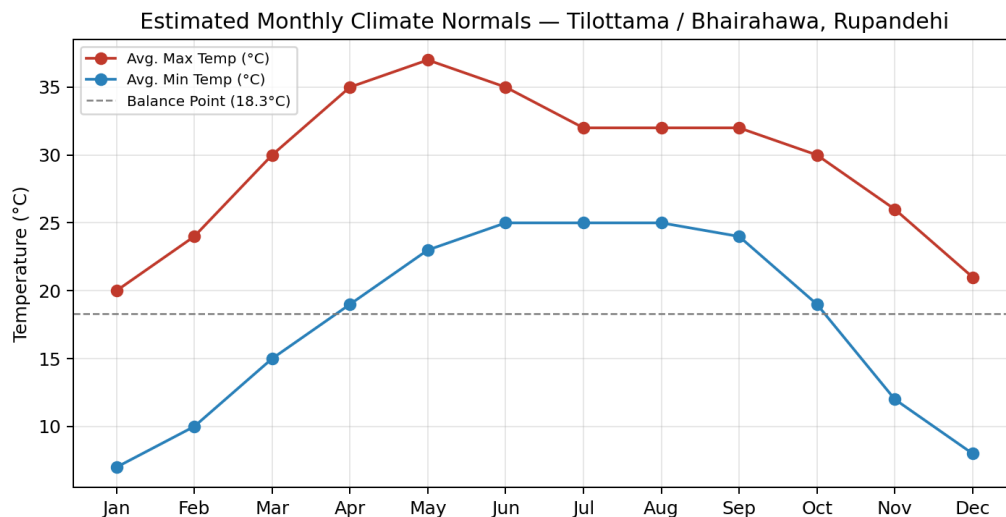
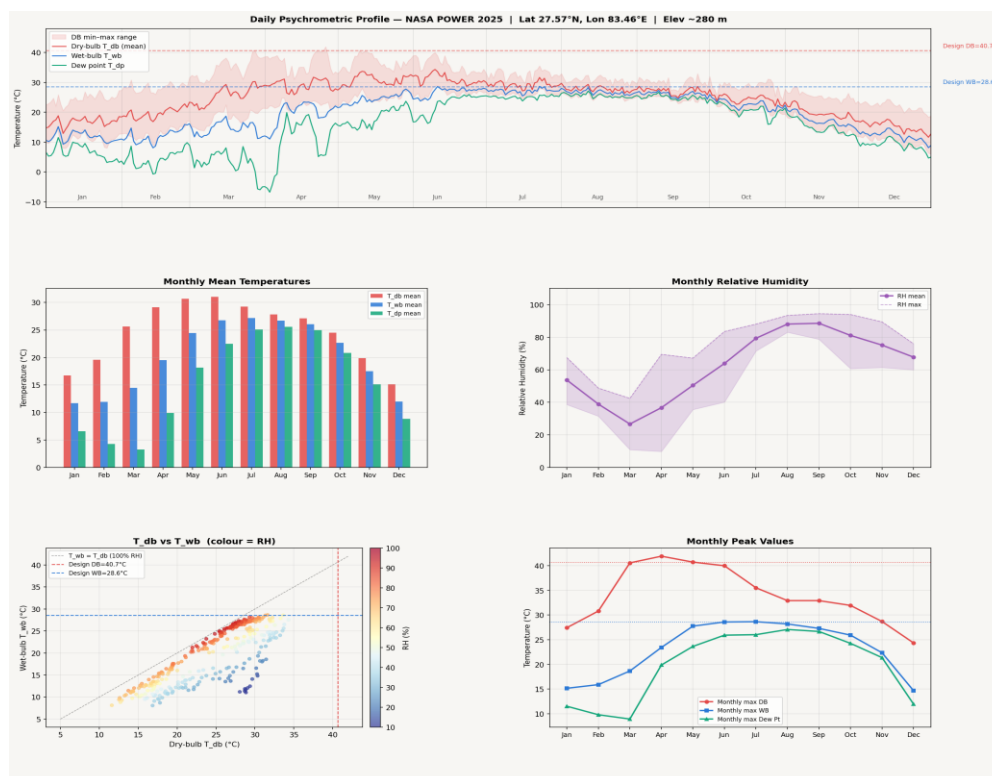


Figure 5.1 — Estimated monthly climate normals for Tilottama/Bhairahawa, with the 18.3 °C (65 °F) balance-point temperature used for the degree-day analysis in Section 5.2.



5.2 Degree-Day Based Energy Estimation Method

Monthly heating and cooling energy demand was estimated with the degree-day method, using an effective building UA (envelope transmission + ventilation/infiltration, derived directly from the Section 3 load calculations) and a balance-point temperature of 18.3 °C (65 °F):

- Effective envelope UA (walls + roof + floor + windows, both rooms): 415.7 Btu/hr·°F = 219.3 W/°C
- Effective ventilation + infiltration UA (both rooms, combined design airflow): 306.8 Btu/hr·°F = 161.9 W/°C
- Total effective building UA: 0.381 kW/°C
- Annual Cooling Degree-Days (base 18.3 °C): $\approx 2,242$ °C·days
- Annual Heating Degree-Days (base 18.3 °C): ≈ 303 °C·days

Monthly thermal energy = UA (kW/°C) $\times$ monthly degree-days $\times$ 24 h/day. This thermal energy was then converted to electrical energy using an assumed seasonal average heat-pump performance of COP $\approx$ 3.2 (cooling) and COP $\approx$ 2.8 (heating), consistent with the inverter heat-pump units selected in Section 4.3.

Note on method limitations: the degree-day method captures transmission and ventilation-driven loads well, but does not independently resolve monthly solar and internal-gain variation the way the peak-day ETD/CLTD calculation in Section 3.3 does. It is therefore best read as a first-order seasonal estimate rather than a substitute for the detailed peak-load calculation used for equipment sizing.

5.3 Monthly Energy Demand

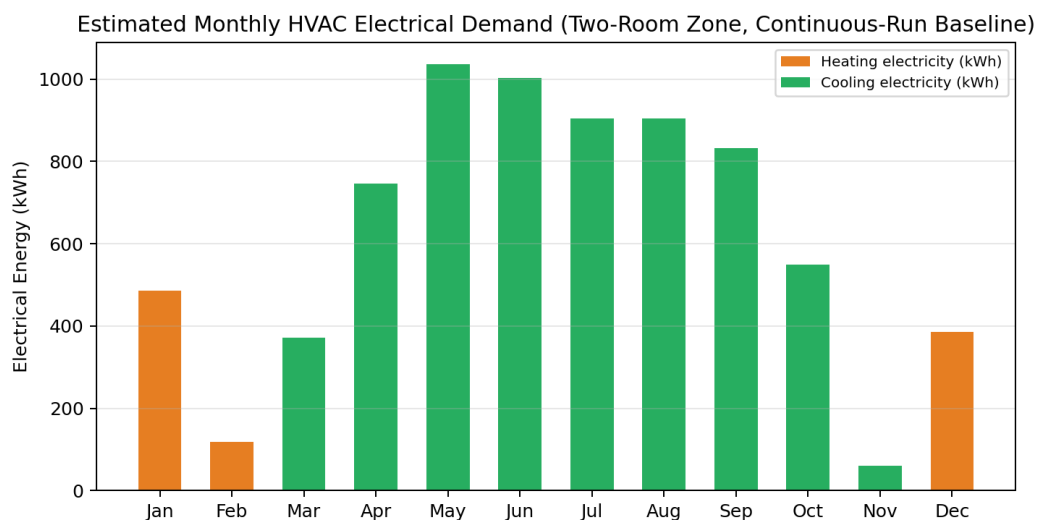


Figure 5.2 — Estimated monthly HVAC electrical demand (continuous-run baseline) for the two-room zone.

Month	Cooling Electricity (kWh)	Heating Electricity (kWh)	Total (kWh)
Jan	0	486.2	486.2
Feb	0	118.9	118.9
Mar	372.4	0	372.4
Apr	746.5	0	746.5

Month	Cooling Electricity (kWh)	Heating Electricity (kWh)	Total (kWh)
May	1,036.8	0	1,036.8
Jun	1,003.3	0	1,003.3
Jul	904.0	0	904.0
Aug	904.0	0	904.0
Sep	831.8	0	831.8
Oct	549.8	0	549.8
Nov	60.0	0	60.0
Dec	0	384.9	384.9
Annual Total	6,408.6	990.0	7,398.6

This is a theoretical continuous-run baseline (equipment assumed to maintain setpoint 24 h/day). In practice, residential HVAC in Nepal typically operates intermittently — commonly 8–10 hours/day for cooling during peak summer evenings/nights and 6–8 hours/day for heating on winter mornings/evenings. Applying a representative 35–45% duty factor gives a more realistic estimated annual consumption of roughly 2,600–3,300 kWh/year for the two-room zone.

5.4 Electrical Demand Profile and Indicative Operating Cost

- Peak cooling month: May ($\approx 1,037$ kWh, continuous-run basis), coinciding with the pre-monsoon hot-dry season — the single highest electrical demand period of the year.
- Peak heating month: January (≈ 486 kWh, continuous-run basis).
- Cooling accounts for $\approx 87\%$ of annual HVAC electricity; heating accounts for $\approx 13\%$ — confirming this is a cooling-dominated climate despite the meaningful winter heating requirement identified in Section 3.2.
- At an indicative Nepal Electricity Authority residential tariff of roughly NPR 10–12/kWh (mid consumption slab), the realistic 2,600–3,300 kWh/year estimate corresponds to an approximate annual HVAC electricity cost of NPR 26,000–40,000 for the two rooms studied; actual tariffs should be confirmed against the current NEA slab rates at the time of billing.

6. Energy Efficiency Improvement Study

Five practical, quantified efficiency measures are proposed below, in order of typical cost-effectiveness. Savings are estimated relative to the annual HVAC electricity baseline of $\approx 7,399$ kWh/year (continuous-run basis, Section 5.3) and an indicative tariff of NPR 10/kWh; a realistic intermittent-use baseline would scale all NPR figures down proportionally but leave the simple payback periods roughly unchanged.

6.1 Measure 1 — Air Sealing and Weatherstripping

Sealing window frames and adding door weatherstripping is estimated to cut combined infiltration (currently 34.1 CFM across both rooms) by roughly 30–40%. This reduces both sensible heating loss and sensible/latent cooling gain.

Metric	Value
Load reduction	≈ 12 CFM infiltration reduction; $\approx 2\%$ of total heating load, $\approx 1\%$ of total cooling load
Estimated annual electricity savings	≈ 110 kWh/year
Estimated cost saving	$\approx$ NPR 1,100/year
Approximate measure cost	NPR 1,500 – 2,000 (weatherstrip tape, sealant)
Simple payback	< 2 years

6.2 Measure 2 — Reflective ('Cool') Roof Coating

A reflective coating on the RCC roof slab reduces solar absorption and effective ETD, cutting roof cooling gain (currently 8,728.5 Btu/hr combined) by an estimated 25% without a full insulation retrofit.

Metric	Value
Load reduction	$\approx 2,182$ Btu/hr (0.64 kW), $\approx 4.3\%$ of total design cooling load
Estimated annual electricity savings	≈ 276 kWh/year
Estimated cost saving	$\approx$ NPR 2,760/year
Approximate measure cost	NPR 15,000 – 20,000 (253 ft ² roof area @ NPR 60–80/ft ²)

Metric	Value
Simple payback	≈ 6–7 years (best paired with Measure 3 for faster combined payback)

6.3 Measure 3 — Roof Insulation Upgrade (PUF/XPS board)

Adding 50 mm rigid PUF/XPS insulation above the RCC slab is estimated to cut the roof U-value from 0.75 to about 0.15 Btu/hr·ft²·°F (an 80% reduction), which — because the roof is the single largest envelope contributor in both the heating and cooling calculations — has the largest single-measure impact of the five studied.

Metric	Value
Effective building UA reduction	≈ 21% of total effective UA (envelope + ventilation)
Estimated annual electricity savings	≈ 1,554 kWh/year
Estimated cost saving	≈ NPR 15,540/year
Approximate measure cost	NPR 35,000 – 40,000 (253 ft ² @ ≈ NPR 150/ft ²)
Simple payback	≈ 2.3–2.5 years

6.4 Measure 4 — External Window Shading (Awnings/Louvres)

Fixed external shading over the West and South windows (the two solar-exposed openings in Room 1, plus the West window in Room 2) can block an estimated 50% of the incident solar heat gain during peak afternoon hours, at a fraction of the cost of glazing replacement.

Metric	Value
Load reduction	≈ 2,105 Btu/hr (0.62 kW) combined solar gain, ≈ 4.2% of total design cooling load
Estimated annual electricity savings	≈ 269 kWh/year
Estimated cost saving	≈ NPR 2,690/year
Approximate measure cost	NPR 6,600 – 13,200 (44 ft ² window area @ NPR 150–300/ft ²)
Simple payback	≈ 3–5 years

6.5 Measure 5 — Double Glazing / Low-E Glass Upgrade

Replacing single-pane ordinary glass with double-glazed Low-E units reduces both conduction (U-value from 0.86 to ≈ 0.45 Btu/hr·ft²·°F) and solar heat gain (SHGC from 0.75 to ≈ 0.35). This is the most capital-intensive of the five measures and, on its own, has the longest payback — best justified when window replacement is needed for other reasons (durability, noise, aesthetics) and the energy saving is a secondary benefit.

Metric	Value
Load reduction	≈ 2,782 Btu/hr (0.82 kW) cooling, ≈ 607 Btu/hr heating
Estimated annual electricity savings	≈ 445 kWh/year
Estimated cost saving	≈ NPR 4,450/year

Metric	Value
Approximate measure cost	NPR 35,000 – 53,000 (44 ft ² window area @ NPR 800–1,200/ft ²)
Simple payback	≈ 8–10 years

6.6 Summary and Recommended Sequence

Measure	Annual Savings (kWh)	Simple Payback
1. Air sealing / weatherstripping	≈ 110	< 2 years
3. Roof insulation (PUF/XPS)	≈ 1,554	≈ 2.3–2.5 years
4. External window shading	≈ 269	≈ 3–5 years
2. Reflective roof coating	≈ 276	≈ 6–7 years
5. Double glazing / Low-E glass	≈ 445	≈ 8–10 years
Combined (all five, non-overlapping)	≈ 2,654 (≈ 36% of baseline)	—

A practical rollout order is: (1) air sealing — near-zero cost, fast payback; (3) roof insulation — largest single impact given the roof's dominant share of both heating and cooling load; (4) external shading — low cost, good return; then (2) reflective roof coating and (5) glazing upgrade as budget allows or when roof/window work is otherwise being carried out. Reflective coating and full insulation are partially overlapping (both target the roof); if budget allows only one, insulation (Measure 3) gives the larger and more durable benefit.

7. Conclusion

The two-room case study demonstrates a cooling-dominated residential thermal profile typical of Nepal's Terai plains: peak design cooling load (55,270 Btu/hr / 4.61 TR combined, with 10% safety factor) is roughly double the peak design heating load (27,140 Btu/hr / 7.95 kW combined). Room 1, with two exterior walls and two windows, consistently carries a higher load than Room 2 in both seasons, confirming the need for zoned, independently controlled equipment rather than a single shared unit.

A reversible inverter heat-pump split system — 3.0 TR for Room 1 and 2.5 TR for Room 2 — meets both the cooling and heating requirements with the standard equipment-sizing margin. The roof is consistently the largest single envelope contributor to both heating and cooling load, making roof insulation the highest-impact, most cost-effective structural improvement identified in Section 6, followed by low-cost measures such as air sealing and external shading. The seasonal energy forecast (Section 5) indicates an annual HVAC electricity requirement in the range of 2,600–3,300 kWh for realistic intermittent operation, with the pre-monsoon months of April–June forming the peak demand period.

Two modeling notes are carried forward for the viva voce discussion: (1) the 125 CFM per-room ventilation assumption (people method, 5 occupants) is a major driver of both loads and should be validated against actual expected occupancy; and (2) the door heat-gain treatment differs slightly between the heating (interior door, zero loss) and cooling (ETDc-based gain) calculations, reflecting a modeling assumption that the space beyond the east-wall door is only partially conditioned/buffered — this should be clarified against the as-built condition of the house.

References

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- [8] Prashant Bhusal, "Cooling Load Calculation — ETD/CLTD Method, Room-by-Room Analysis," course assignment worksheet, Kathmandu University, 2026.

Appendix A: Detailed Formula-Level Load Calculations

This appendix reproduces the governing equations and step-by-step substitutions used to generate the summary tables in Section 3, serving as the load calculation sheet for this study.

A.1 Governing Equations

- Transmission heat transfer: $Q = U \times A \times \Delta T$ (heating) or $Q = U \times A \times \text{ETDc}$ (cooling), where $\text{ETDc} = \text{ETD} + \text{correction factor}$.
- Infiltration/ventilation sensible heat: $Q_s = 1.08 \times \text{CFM} \times \Delta T$.
- Infiltration/ventilation latent heat: $Q_L = 0.68 \times \text{CFM} \times (W_o - W_i)$, where W is humidity ratio (grains/lb) read from the psychrometric chart.
- Solar heat gain through glass: $Q = \text{SHGC} \times \text{Solar Radiation Intensity} \times \text{Window Area}$.
- People heat gain: $Q_s = N \times (\text{sensible heat/person})$, $Q_L = N \times (\text{latent heat/person})$; 230 Btu/hr sensible and 120 Btu/hr latent per person adopted for light residential activity.
- Infiltration by crack method: $\text{CFM} = (\text{window perimeter} \times \text{infiltration rate}) + (\text{door area} \times \text{infiltration rate})$.
- Ventilation by people method: $\text{CFM} = \text{number of occupants} \times \text{CFM/person}$ (25 CFM/person used); checked against the area method ($\text{CFM} = \text{floor area} \times 0.25$) and the higher value governs.
- Wall/roof resistance build-up: $\Sigma R = R(\text{outside air film}) + R(\text{materials}) + R(\text{inside air film})$; $U = 1/\Sigma R$.

A.2 Room 1 (Living Room) — Cooling Load Derivation

Wall resistance build-up: $\Sigma R = 2.85 \text{ hr} \cdot \text{ft}^2 \cdot ^\circ\text{F}/\text{Btu} \rightarrow U = 1/2.85 = 0.35 \text{ Btu/hr} \cdot \text{ft}^2 \cdot ^\circ\text{F}$. $\text{ETDc} = \text{ETD} + \text{correction} = 12 + 14 = 26 ^\circ\text{F}$.

Step	Calculation	Result
Glass conduction	$0.86 \times (12 + 20) \times (106.67 - 77)$	816.52 Btu/hr
Glass solar (West)	$0.75 \times 163 \times 12$	1,467.00 Btu/hr
Glass solar (South)	$0.75 \times 85 \times 20$	1,275.00 Btu/hr
Wall — West	$0.35 \times (130 - 12) \times (12 + 14)$	1,073.80 Btu/hr
Wall — South	$0.35 \times (110 - 20) \times (12 + 14)$	819.00 Btu/hr
Partition wall q1	$0.35 \times 110 \times ((106.76 - 5) - 77)$	949.80 Btu/hr
Partition wall q2	$0.35 \times (110 + 18) \times ((106.76 - 5) - 77)$	794.37 Btu/hr
Floor	$0.32 \times 143 \times ((106.76 - 5) - 77)$	1,128.89 Btu/hr
Roof	$0.75 \times 143 \times (32 + 14)$	4,933.50 Btu/hr
Door	$0.39 \times 18 \times (40 + 14)$	379.08 Btu/hr
Lighting	$(12 + 9) \times 1.11 \times 1.25 \times 3.4$	99.07 Btu/hr
People (5 occupants)	$q_s = 5 \times 230$; $q_L = 5 \times 120$	1,150.00 / 600.00 Btu/hr
Infiltration CFM	$9 (\text{door}) + 4.9 (W1) + 6.3 (W2)$	20.2 CFM
Infiltration Q_s / Q_L	$1.08 \times 20.2 \times 29.67$ / $0.68 \times 20.2 \times 76$	649.24 / 1,043.94 Btu/hr
Ventilation CFM (people method)	5×25 (governs over area method 35.75)	125 CFM

Step	Calculation	Result
Ventilation Qs / QL	$1.08 \times 125 \times 29.67 / 0.68 \times 125 \times 76$	4,017.60 / 6,460.00 Btu/hr

A.3 Room 2 (Secondary Room) — Cooling Load Derivation

Step	Calculation	Result
Glass conduction	$0.86 \times 12 \times (106.76 - 77)$	307.12 Btu/hr
Glass solar (West)	$0.75 \times 163 \times 12$	1,467.00 Btu/hr
Wall — West	$0.35 \times 88 \times (12 + 14)$	880.80 Btu/hr
Partition wall (North)	$0.35 \times 110 \times ((106.76 - 5) - 77)$	953.26 Btu/hr
Floor	$0.32 \times 110 \times ((106.76 - 5) - 77)$	871.55 Btu/hr
Roof	$0.75 \times 110 \times (32 + 14)$	3,795.00 Btu/hr
Door	$0.39 \times 18 \times (40 + 14)$	379.08 Btu/hr
Lighting	$(12 + 9) \times 1.11 \times 1.25 \times 3.4$	99.07 Btu/hr
People (5 occupants)	$q_s = 5 \times 230$; $q_L = 5 \times 120$	1,150.00 / 600.00 Btu/hr
Infiltration CFM (crack method)	window perimeter $14 \text{ ft} \times 0.35$ + door $18 \text{ ft}^2 \times 0.5$	13.9 CFM
Infiltration Q_s / Q_L	$1.08 \times 13.9 \times 29.67$ / $0.68 \times 13.9 \times 76$	446.76 / 718.35 Btu/hr
Ventilation CFM (people method)	5×25 (governs over area method 27.5)	125 CFM
Ventilation Q_s / Q_L	$1.08 \times 125 \times 29.67$ / $0.68 \times 125 \times 76$	4,017.60 / 6,460.00 Btu/hr

A.4 Room-by-Room Heating Load Derivation (Steady-State UA Method)

Design $\Delta T = 77 - 42.85 = 34.15$ °F, applied uniformly. Interior partitions and interior doors carry $\Delta T \approx 0$ and are excluded.

Component	Room 1 Calculation	Room 2 Calculation
Wall	$0.35 \times 208 \times 34.15 = 2,486.12$	$0.35 \times 98 \times 34.15 = 1,171.35$
Window	$0.86 \times 32 \times 34.15 = 939.81$	$0.86 \times 12 \times 34.15 = 352.43$
Roof	$0.75 \times 143 \times 34.15 = 3,662.59$	$0.75 \times 110 \times 34.15 = 2,817.38$
Floor	$0.32 \times 143 \times 34.15 = 1,562.70$	$0.32 \times 110 \times 34.15 = 1,202.08$
Infiltration	$1.08 \times 20.2 \times 34.15 = 744.99$	$1.08 \times 13.9 \times 34.15 = 512.66$
Ventilation	$1.08 \times 125 \times 34.15 = 4,610.25$	$1.08 \times 125 \times 34.15 = 4,610.25$

All values in Btu/hr. Subtotals are increased by a 10% safety factor to obtain the final design heating loads shown in Section 3.2, and converted to SI units using $1 \text{ Btu/hr} = 0.293071 \text{ W}$.

A.5 Effective Building UA Derivation (used in Section 5.2)

Quantity	Room 1	Room 2	Combined
Envelope UA (wall+window+roof+floor), Btu/hr·°F	253.35	162.31	415.66
Ventilation + infiltration UA equivalent, Btu/hr·°F	$1.08 \times 145.2 = 156.8$	$1.08 \times 138.9 = 150.0$	306.8 *
Total effective UA, Btu/hr·°F	—	—	722.5
Total effective UA, W/°C	—	—	381.2

* Combined ventilation + infiltration airflow = $(20.2 + 125) + (13.9 + 125) = 284.1$ CFM; UA-equivalent = $1.08 \times 284.1 = 306.8$ Btu/hr·°F. Conversion to SI: $UA(W/^{\circ}C) = UA(Btu/hr \cdot ^{\circ}F) \times 0.5275$.