

Design and Energy-Economic Evaluation of a Pellet-Solar Heating System for Single-Family Houses using DIN EN 12831 in Wagate-Papua

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Article Information	ABSTRACT
Article History Received : June 24, 2026 Revised : July 10, 2026 Published : July 20, 2026	This study presents the design and thermal analysis of a heating and ventilation system for a residential single-family house located in Wagate, Kabupaten Deiyai, Provinsi Papua Tengah, Indonesia, using the calculation procedures specified in DIN EN 12831. The design heating load was calculated to be 6,560 W, comprising transmission heat losses of 4,232 W, ventilation losses of 1,097 W, and an additional reheating capacity of 1,231 W. A pellet boiler (ETA Pellets Unit 7, 2.3–7.7 kW) combined with a flat-plate solar thermal system (4 collectors, total absorber area 9.4 m²) was selected as the heat generation system. Underfloor heating was designed for all rooms using wet-screed pipe systems (Variotherm, 16 mm aluminum composite pipes), supplemented by wall-mounted radiators in the bathroom (248 W) and shower (38 W). The annual heat demand was determined to be 17,756 kWh/a, with the solar system contributing 4,935 kWh/a (27.8%). Annual CO₂ emissions were estimated at 4,283 kg/a. The system complies with all requirements of the Energieeinsparverordnung (EnEV, 2014) and the Erneuerbare-Energien-Wärmegesetz (EEWärmeG, 2014), with a specific transmission heat loss of $H'T = 0.29 \text{ W/(m}^2\cdot\text{K)}$, well below the $0.4 \text{ W/(m}^2\cdot\text{K)}$ limit. The methodology presented here provides a systematic, replicable framework for residential building energy system design in temperate climates, with direct relevance for energy system planning in remote highland communities in Papua Tengah, Indonesia.
Keywords: <i>DIN EN 12831;</i> <i>Energy efficiency;</i> <i>Heating load;</i> <i>Pellet boiler;</i> <i>Solar thermal collector.</i>	

INTRODUCTION

Thermal conditioning in residential homes in regions with four seasons, such as in Europe, or in mountainous areas like Wagate, Central Papua Province, Indonesia, always presents a unique challenge (Kamel & Memari, 2022). Consequently, this poses a unique challenge in designing an efficient heating system that complies with engineering and energy policy standards and regulations. In the case of Germany, regulations related to renewable energy—known as the Erneuerbare-Energien-Wärmegesetz (EE-WärmeG)—and regulations related to energy conservation—the Energieeinsparverordnung (EnEV)—both enacted in 2014, serve as the two key reference frameworks in the country's energy policy (Bundesrepublik Deutschland, 2008; Bundesrepublik Deutschland, 2013). The objectives of these two fairly specific regulations in the energy sector are (1) to require new power generation facilities to meet their heat requirements from renewable energy sources; (2) to limit the use of primary energy and excessive specific transmission heat loss (Bundesministerium für Wirtschaft und Energie, 2013; Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit, 2015). With the establishment of these systematic policies and guidelines, engineers are required to integrate them into the planning,

installation, and maintenance of residential heating, ventilation, and hot water systems, as well as into the calculation of normative heat loads, system sizing, and periodic and continuous economic-ecological assessments (Deutsches Institut für Normung, 2003; Verein Deutscher Ingenieure, 2021).

In Europe, to this day, the design of space-heating, ventilation, and hot-water systems in seasonally heated residential homes largely follows the standards in effect on the continent, namely DIN EN 12831 (Deutsches Institut für Normung, 2003). Previous studies have shown that in Europe, the integrated use of biomass boilers fueled by wood pellets and solar panel heat collectors can significantly reduce dependence on primary energy and significantly lower CO₂ emissions compared to fossil fuel-based systems, while also accommodating the use of heat for underfloor heating (Allahseh et al., 2025; Sevindik et al., 2021; Kim & Kim, 2019; Chandramohan & Das, 2023). Nevertheless, the separation of calculations between heat load and economic and environmental impact assessments for the integrated installation of a wood pellet biomass boiler and solar panel collectors—as modeled in a single-family home in previous studies—makes the model in this study important for further investigation (Kamel & Memari, 2022; Attia et al., 2022).

A building is considered energy-efficient if it can generate, store, and consume energy independently. According to Faraj et al. (2021), phase-change materials can help improve indoor thermal comfort while reducing excessive primary energy consumption. Furthermore, Gaurav and Verma (2024) concluded that advances in solar mass collector technology now offer greater opportunities to directly harness solar heat to meet a building's thermal needs, thereby making it more energy-independent. Additionally, Hardiatama et al. (2024) demonstrated that temperature control can improve energy conversion efficiency in solar power systems. In another study, Hardiatama et al. (2024) demonstrated that regulating the inlet and outlet temperatures (Soll and Ist) in solar thermal energy conversion systems can improve system efficiency. Nozari et al. (2022) also note that the key components for regulating the efficiency of residential solar thermal energy systems are temperature control devices, heat storage devices, and energy management systems. This is particularly important for reliable and cost-effective heating in two-story homes in Waghete, Papua.

DIN EN 12831 is commonly used for heating load calculations in European residential buildings, but previous studies have primarily focused on heating load estimation or specific technologies in European climates. There has been limited research on integrating heating load calculations, hydraulic distribution design, domestic hot water production, renewable energy systems, economic feasibility, and environmental performance within a single residential model (Kotte, L. et al., 2024; Deutsches Institut für Normung, 2017). Furthermore, studies applying DIN EN 12831 in tropical highland regions, where low ambient temperatures necessitate space heating despite the region's tropical location, remain scarce. Consequently, there remains a lack of integrated design frameworks that combine DIN EN 12831-based heating load calculations with pellet boiler systems, solar thermal collectors, EnEV energy performance assessment, life-cycle economic evaluation, and CO₂ emission analysis for residential buildings in tropical mountainous environments such as Waghete, Central Papua. The main components of this study include: (1) determining the design heating load in accordance with DIN EN 12831 for the mountainous context of Central Papua; (2) determining the sizing of distribution pipes, underfloor heating systems, and additional wall radiators; (3) selecting a wood-pellet boiler and a solar thermal system; and (4) verifying compliance with EnEV regulations through specific transmission loss and primary energy demand assessments, along with an evaluation of economic factors and CO₂ emissions. By using a fully operational example, this study aims to demonstrate how a pellet-solar heating concept can effectively meet the technical, financial, and regulatory requirements for residential construction in temperate climates.

RESEARCH METHODS

The research focuses on quantitative engineering design in accordance with DIN EN 12831 for a two-story single-family home model in the mountainous region of Central Papua, at an elevation of 1,700 meters above sea level (Deutsches Institut für Normung, 2003). This house

has a minimum design outdoor temperature of -16 °C and an average annual outdoor temperature of 6.3 °C, as reported by the BMKG for 2025. This house has fourteen rooms, each with an indoor design temperature determined in accordance with DIN EN 12831, ranging from 15 to 24 °C (see Table 1 and Figures 1 a), 1b), and 2).

The research methodology was organized into ten sequential stages, as illustrated in Figure 3. First, the research problem was identified by recognizing the need for an integrated residential heating system suitable for the cold, mountainous climate of Waghete, Central Papua, while meeting the engineering requirements of DIN EN 12831, EnEV 2014, and EEWärmeG 2014. Second, a comprehensive literature review and standard selection were conducted to establish the theoretical and regulatory framework for the building heating system design.

Third, the required input data were collected, including architectural drawings, room dimensions and functions, local climatic conditions, thermophysical properties of the building envelope, and technical specifications of the selected heating equipment. Fourth, the boundary conditions for the design calculations were established by defining the indoor design temperatures for each room, the outdoor design temperature, the reference-building U-values, the shielding coefficient ($e = 0.02$), the minimum air-change rate ($n_{\min} = 0.5 \text{ h}^{-1}$), the building airtightness ($n_{50} = 3 \text{ h}^{-1}$), and the height-correction factor ($\epsilon = 1$), in accordance with DIN EN 12831 (Deutsches Institut für Normung, 2003; Deutsches Institut für Normung, 2017). The steady-state temperatures of the two unheated rooms were determined using a heat-balance equation that accounted for both incoming and outgoing heat flows.

Fifth, the design heating load was calculated in accordance with DIN EN 12831 by evaluating transmission and ventilation heat losses and additional reheating power (Deutsches Institut für Normung 2017). Transmission losses were determined using the corrected U-values, which included a thermal-bridge allowance of $0.05 \text{ W}/(\text{m}^2 \cdot \text{K})$, together with the net building-envelope area and the indoor-outdoor temperature difference (Kamel & Memari, 2022). Heat losses to the ground were calculated using the correction factor f_{g2} and an interpolated equivalent U-value, while ventilation losses were taken as the greater of the infiltration heat loss and the minimum ventilation heat loss prescribed by the standard (Verbeke & Audenaert, 2018).

Sixth, the space-heating distribution system was designed based on the calculated room heating demand. A wet-screed underfloor heating system using 16-mm aluminium-composite pipes was selected as the primary heating emitter. Pipe spacing was determined according to the manufacturer's heat-output tables for laminate and ceramic floor finishes (Variotherm Heiz- und Kühlsysteme GmbH, 2017). Additional wall-mounted panel radiators were installed in rooms where the required heat output exceeded the maximum capacity of the underfloor heating system, particularly in the bathroom and shower room (Zhou et al., 2022; Buderus, 2016). The diameters of the main distribution pipes connecting the manifolds to the buffer storage tank were selected to maintain a maximum water velocity of 0.8 m/s (Variotherm Heiz- und Kühlsysteme GmbH, 2017).

Seventh, the renewable heat-generation system was selected by integrating a wood-pellet boiler (2.3-7.7 kW) with a flat-plate solar thermal collector system, with 15% of the annual heat demand as required by EEWärmeG (Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit, 2015; ETA Heiztechnik, 2017; Alam et al., 2021). The pellet boiler was sized to satisfy the entire design heating load, whereas the solar collector field was designed to supply at least 15% of the annual heating demand, thereby fulfilling the EEWärmeG requirements.

Eighth, the overall system performance was evaluated by calculating the annual space-heating demand, domestic hot-water demand, storage and distribution losses, annual pellet consumption, electricity consumption, operating costs, investment costs, solar energy contribution, and annual CO₂ emissions (Schumacher & Nussbaumer, 2023; Kuptz et al., 2022; Verein Deutscher Ingenieure, 2021; Qin, Q. and Gosselin; L., 2023).

Ninth, the designed heating system was verified against the regulatory requirements of EnEV 2014 and EEWärmeG 2014. The calculated specific transmission heat loss (H'T), primary

energy demand, and renewable energy contribution were compared with those of the reference building to confirm compliance with the applicable German energy-performance regulations (Bundesministerium für Wirtschaft und Energie, 2013; Attia et al., 2022).

Finally, the results were synthesized to present the complete heating system configuration, along with its thermal performance, energy efficiency, economic feasibility, environmental impact, and regulatory compliance, thereby demonstrating the applicability of the proposed pellet-solar heating system for residential buildings in tropical highland regions.

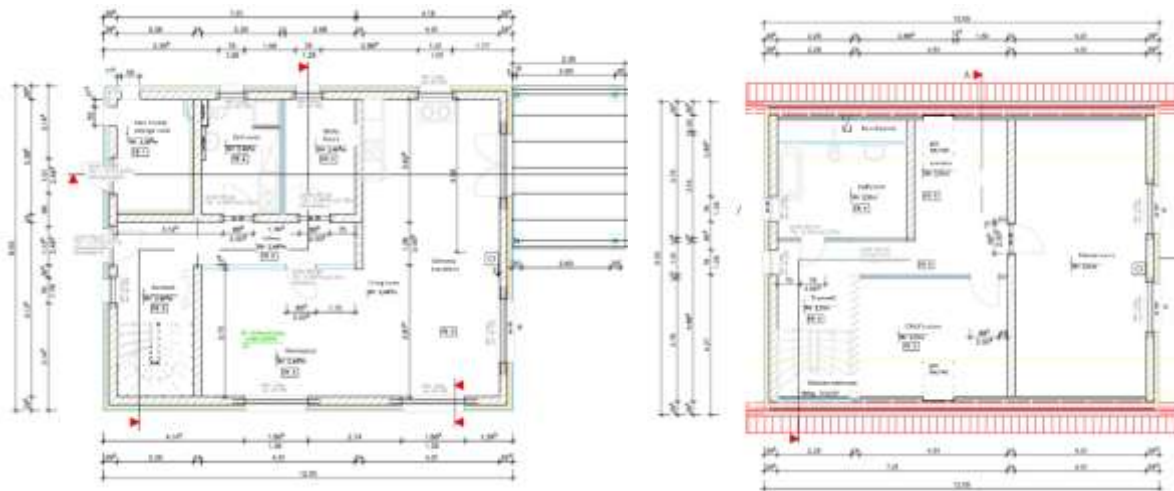


Figure 1. a) The ground floor of the house; b) The upper floor of the house

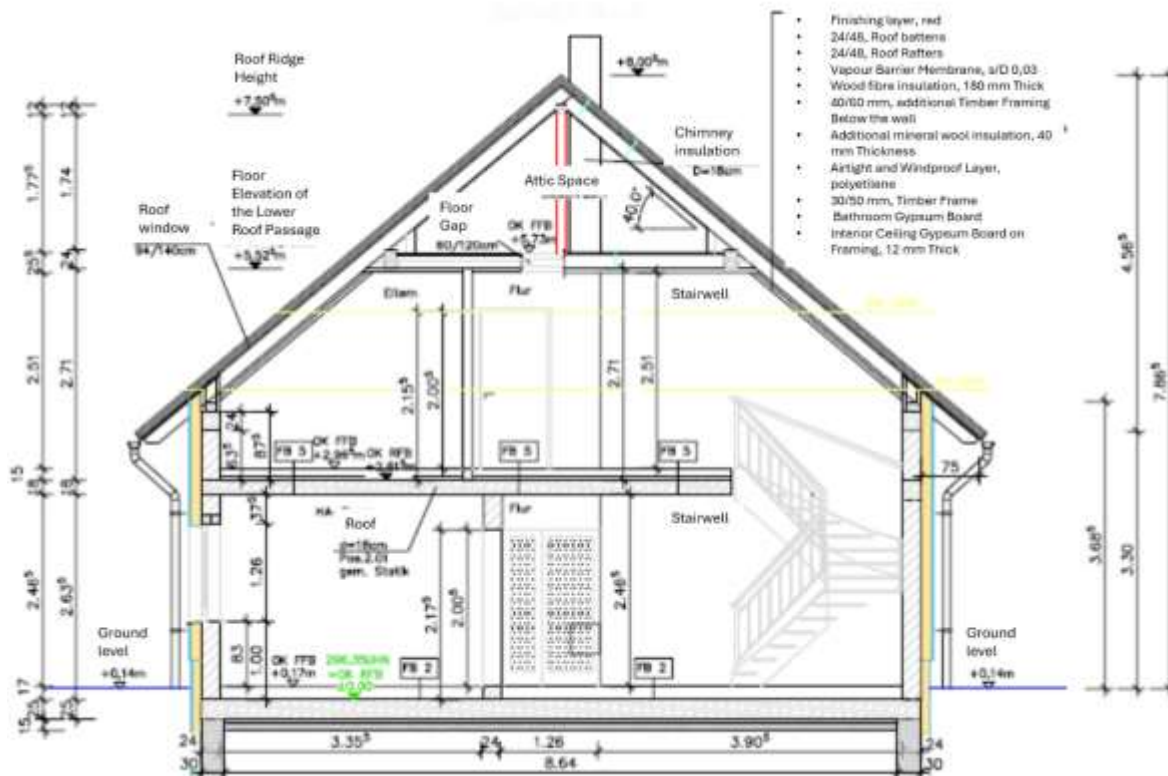


Figure 2. Side view of the house

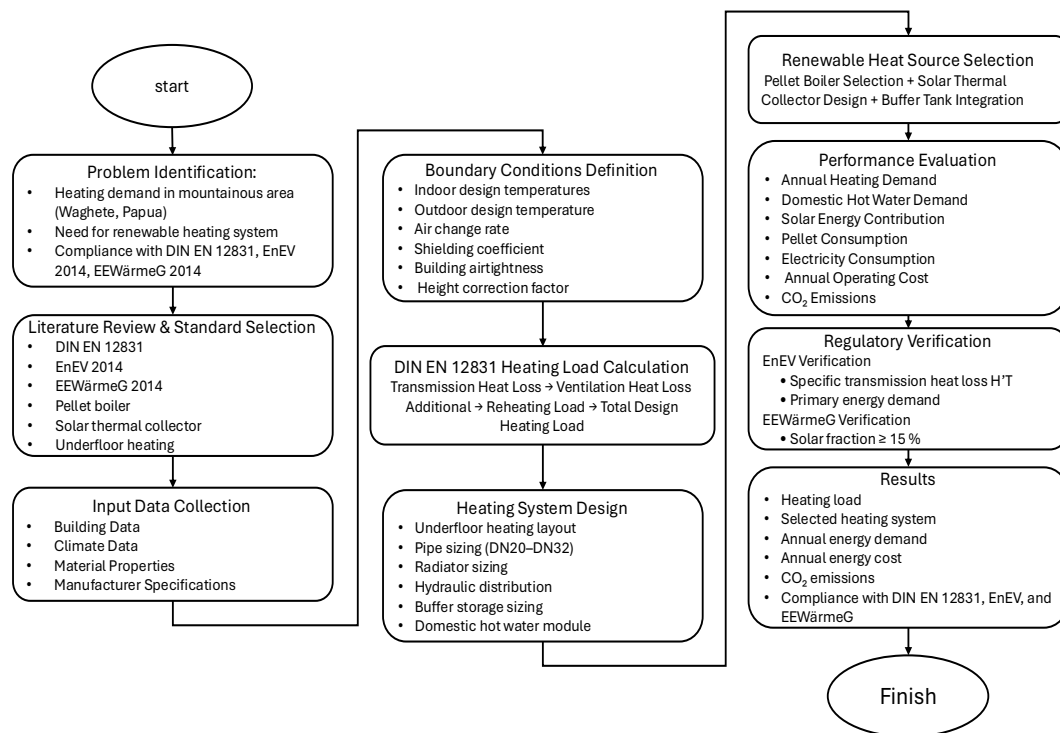


Figure 3. Design Procedure

Below is a summary of the governing equations used in the computation. Equation 1 states that the transmission losses ($\Phi_{T,Geb}$) and ventilation losses ($\Phi_{V,Geb}$) add up to the typical building heat load ($\Phi_{HL,Geb}$) (Recknagel et al., 2018; Deutsches Institut für Normung, 2003).

$$\Phi_{HL,Geb} = \Phi_{T,Geb} + \Phi_{V,Geb} \quad (1)$$

Equation 2 calculates the transmission loss of a component to outdoor air (Φ_{Ti,U_m}) using the net area, corrected U-value, shielding coefficient (U_C), and indoor-outdoor temperature difference.

$$\Phi_{Ti,U_m} = A_{Netto} U_C (\vartheta_{int} - \vartheta_e) \quad (2)$$

Equation 3 states that the corrected U-value increases the physical U-value by a thermal-bridge allowance ΔU_{WB} .

$$U_C = U + \Delta U_{WB} \quad (3)$$

Equation 4 defines ventilation heat loss, or $\Phi_{V,Geb}$, as the greater of the loss from natural infiltration and the minimum needed air-change rate:

$$\Phi_{V,Geb} = \text{Max}(\Phi_{V,min,Geb}, \Phi_{Inf,Geb}) \quad (4)$$

The room area A and the reheat factor, f_{RH} , are used to calculate the additional reheat power for intermittently heated rooms, Φ_{RH} (Equation 5):

$$\Phi_{RH} = A f_{RH} \quad (5)$$

Equation 6 states that the standard heat load ($\Phi_{HL,Geb}$) and the reheat power ($\Phi_{RH,Geb}$) add up to the design heating load ($\Phi_{Ausleg,Geb}$) utilized for heat-generator selection.

$$\Phi_{\text{Ausleg,Geb}} = \Phi_{\text{HL,Geb}} + \Phi_{\text{RH,Geb}} \quad (6)$$

The heat-transferring envelope area A normalizes the total transmission loss coefficient, H_T , using the specific transmission heat loss, H'_T , which is needed for EnEV certification (Equation 7):

$$H'_T = H_T/A \quad (7)$$

The purpose of this calculation is to verify that the reference building's energy demand, $Q_{p,\text{ref}}$, must not be exceeded by the building's annual primary energy demand, $Q_{p,\text{ist}}$, a value that depends, among other factors, on the primary energy factor specific to the energy carrier $f_{p,\text{ist}}$, such as wood pellets.

$$Q_{p,\text{ist}} = (Q_{\text{Pellet}} - Q_{\text{Solar}}) f_{p,\text{ist}} + W_{\text{el}} 1,8 \leq Q_{p,\text{ref}} = 0,75 \left((Q_H + Q_V) f_{p,\text{ref}} + W_{\text{el}} 1,8 \right) \quad (8)$$

RESULTS AND DISCUSSION

Boundary Conditions and Design Heating Load

Table 1. Indoor design Temperatures by room (DIN EN 12831)

Room	Design Temperature [°C]
Living room	20
Study room	20
Parents' bedroom	20
Children's bedroom	20
Lower hallway	15
Utility room	15
Staircase	15
Upper hallway	15
Bathroom	24
Shower room	24
Attic/loft	6

Table 1 lists the design temperatures for each room included in the heating load calculation model. Rooms with high humidity are set to 24 °C, circulation areas to 15 °C, and frequently used rooms, such as living rooms, study rooms, and bedrooms, to 20 °C. Meanwhile, the U-Values for the building envelope components are shown in Table 2 with a uniform tolerance of 0.05 W/(m² K), calculated using Equation (3) in accordance with DIN EN 12831 (Bundesministerium für Wirtschaft und Energie, 2013).

Table 2. Reference-building U-values of the building envelope

Component	U-value [W/(m ² K)]	Thermal bridge ΔU [W/(m ² K)]
Exterior wall	0.28	0.05
Floor slab	0.35	0.05
Roof	0.20	0.05
Window/French door	1.30	0.05
Roof window	1.40	0.05

Component	U-value [W/(m ² K)]	Thermal bridge ΔU [W/(m ² K)]
Exterior door	1.80	0.05

Applying these boundary conditions to the fourteen rooms in the house results in a typical building heat load of 5329 W, with a transmission heat loss of 4232 W and a ventilation heat loss of 1097 W. The six rooms with intermittent heating (living, study, parents', children's, bathroom, shower) have a design heating load of 6560 W (see Table 3) (Deutsches Institut für Normung, 2017) when the reheat power of 1231 W—calculated for an 8-hour non-occupancy period (5 h setback, 3 h reheat). The building envelope, which is dominated by the 0.20-0.35 W/(m²K) U-values of the roof and floor slab, is confirmed to perform near the regulatory reference by this value (Attia et al., 2022; Kamel & Memari, 2022). Its size is comparable to the design loads documented for single-family dwellings of similar size constructed in accordance with the EnEV 2014 guidelines.

The resulting specific transmission heat loss of $H'_T = 0.29 \text{ W/(m}^2\text{K)}$ is much below the EnEV maximum of $0.40 \text{ W/(m}^2\text{K)}$ applicable to buildings with a useable floor area not exceeding 350 m² prior to the implementation of any active system measures (see Table 3), demonstrating an envelope that complies with heat loss regulations (Bundesministerium für Wirtschaft und Energie, 2013; Attia et al., 2022).

Table 3. Design heating load and specific transmission heat loss results

Component	Value
Transmission heat loss, $\Phi_{T,Geb}$	4232 W
Ventilation heat loss, $\Phi_{V,Geb}$	1097 W
Reheat power, $\Phi_{RH,Geb}$	1231 W
Design heating load, $\Phi_{Ausleg,Geb}$	6560 W
Specific transmission heat loss, H'_T	$0.29 \text{ W/(m}^2\text{K)}$
EnEV maximum $H'_{T,Max}$ ($A_N \leq 350 \text{ m}^2$)	$0.40 \text{ W/(m}^2\text{K)}$

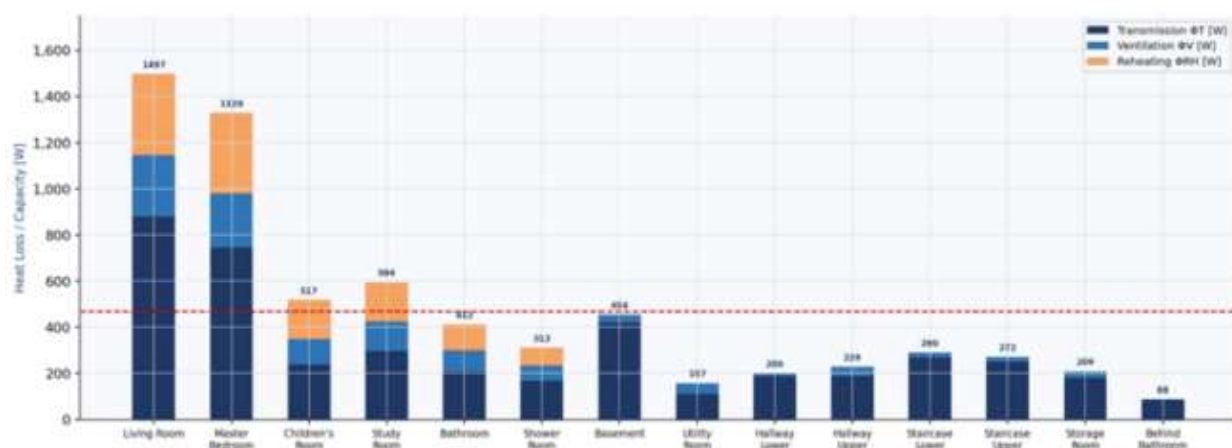


Figure 4. Room-level design heat demand, ranked from highest to lowest

The primary reason for the extra radiators discussed in the next part is the disproportionately high demand in the bathroom and shower room, given their compact size. As shown above, due to their large floor area, the living and parents' bedrooms account for most of the total heat demand (see Figure 4).

Sizing of Heat-Emitting Components

It was discovered that nine of the eleven heated zones had sufficient floor heating, which was intended for a 35/30 °C supply/return temperature; pipe spacings ranging from 100 mm (bathroom, shower) to 300 mm (storage room) were selected by comparing the manufacturer's output curves for laminate and tile finishes with the area-specific heat demand (Variotherm Heiz- und Kuhlssysteme GmbH, 2017). However, because the area-specific heat demand (73 and 51 W/m², respectively) exceeded the maximum floor-heating output of 46 W/m² at 24 °C, additional panel radiators of 248 W and 38 W, respectively, were added in the bathroom and shower room (Table 4). This exemplifies a typical drawback of low-temperature floor heating in tiny, hot, moist rooms (Liao et al., 2022)

The distribution pipes between the buffer tank and the three manifold cabinets (ground floor, upper floor, and attic, see Table 4) are therefore designed for a maximum velocity of 0.8 m/s using pipes with nominal diameters of DN32 for the ground floor (which carries the combined flow for the entire building), DN25 for the upper floor, and DN20 for the attic circuit. This is in line with the expected reduction in transferred heat flow at each branch point (Variotherm Heiz- und Kuhlssysteme GmbH, 2017).

Table 4. Main heat-generation and distribution components selected

Component	Specification
Heat Generation Unit	ETA PU7 Pellet Boiler with Integrated Mixing Circuit (ETA Heiztechnik., 2017)
Thermal Energy Storage	ETA Solar SPS825 Stratified Buffer Tank (825 L)
Domestic Hot Water Preparation	ETA FWM-E Fresh Water Module
Solar Thermal Collector Field	Buderus SKT 1.0-s Solar Collectors with Pump Station and Expansion Vessel (Buderus SKT 1.0-s., 2016)
System Filling and Backflow Protection	WS DN15 Type BA Automatic Filling Valve
Hydraulic Protection	Buderus Logafix Magnetic Dirt Separator
Pressure Control	Flamco 80 L Expansion Vessel
Space Heating (Bathrooms)	Logatrend VC Series Panel Radiators
Hydronic Distribution	EMPUR Manifold Cabinets with HKV Distribution Manifolds
Underfloor Heating System	Schütz Quadro-Takk EPS-T30-3 with PE-Xa 16×2 mm Pipes
Additional Floor Insulation	EPS DEO WLG035 (30 mm)
Pellet Fuel Storage	ETABox Pellet Storage Unit (12 Bags Capacity)
Main Distribution Piping	Copper Pipes DN32, DN25, and DN20
Heat Generation Unit	ETA PU7 Pellet Boiler with Integrated Mixing Circuit
Thermal Energy Storage	ETA Solar SPS825 Stratified Buffer Tank (825 L)
Domestic Hot Water Preparation	ETA FWM-E Fresh Water Module

Heat Generation, Annual Energy, and Economic-Ecological Performance

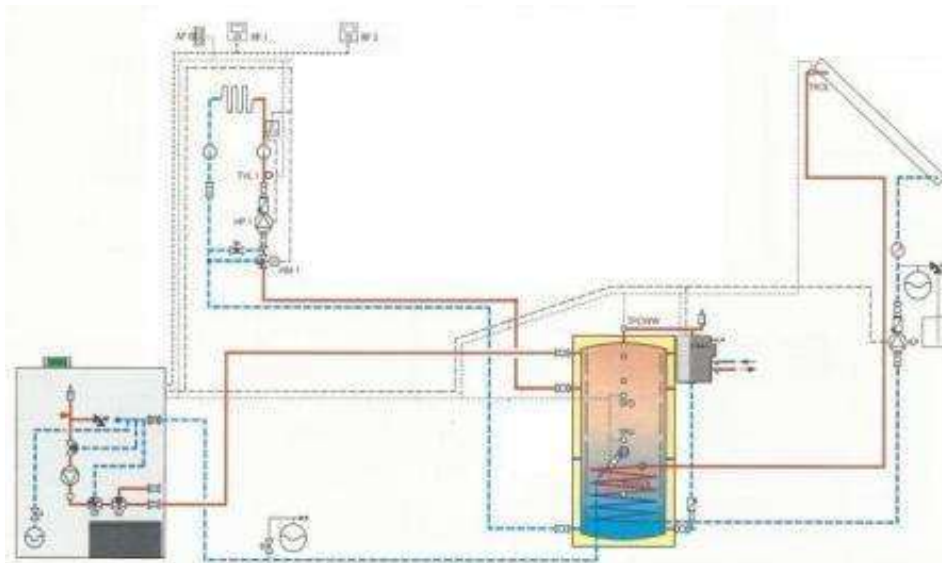


Figure 5. Schematic diagram of the pellet boiler, buffer storage tank, and solar thermal circuit

The buffer storage tank in Figure 5 is directly connected to the pellet boiler, while an independent heat exchanger located inside the tank serves the solar circuit (see Figure 5). To prioritize solar energy use, the boiler's return line is positioned above the heat exchanger, preventing the boiler from fully charging the buffer tank. The heating system is regulated based on the outside temperature, and residential hot water is supplied by a freshwater station that draws from the warmest zone of the tank (Verein Deutscher Ingenieure, 2021).

Table 5. Annual energy demand, cost, and CO₂ emissions

Parameter	Result
Annual heating demand, Q_H	14107 kWh/a
Annual DHW demand, Q_{WW}	2034 kWh/a
Storage/distribution losses, Q_V (10%)	1614 kWh/a
Total annual heat demand, Q_p	17756 kWh/a
Solar collector yield, $Q_{\text{Solar-ist}}$ (4 collectors, 9.4 m ²)	4935 kWh/a (27.8%)
Annual electricity demand, W_{el}	7000 kWh/a
Pellet mass required, m_{Pellets}	2.6 t/a
Annual energy cost (pellets + electricity)	2419 EUR/a
Total CO ₂ emissions, E	4283 kg/a
Primary energy demand (actual), $Q_{p,ist}$	15164 kWh/a
Primary energy demand (reference), $Q_{p,ref}$	20068 kWh/a

The selected ETA Pellets Unit 7 boiler (2.3-7.7 kW nominal output) sufficiently meets the 6.56 kW design heating load with a buffer for domestic hot-water priority operation (Schumacher & Nussbaumer, 2023). 79% of the annual heat demand of 17,756 kWh is accounted for by space heating (Table 5; Figure 6), with the remaining fraction coming from storage/distribution losses (1,614 kWh/a) and residential hot water (2,034 kWh/a). Four Logasol SKT 1.0 flat-plate collectors (9.4 m² total absorber area) in Table 5 supply an estimated 4935 kWh/a, or 27.8% of the

yearly heat requirement. This leaves a comfortable compliance margin, as it is well above the 15% minimum required by EEWarmeG Section 3 (Alam et al., 2021; Kalair et al., 2022).

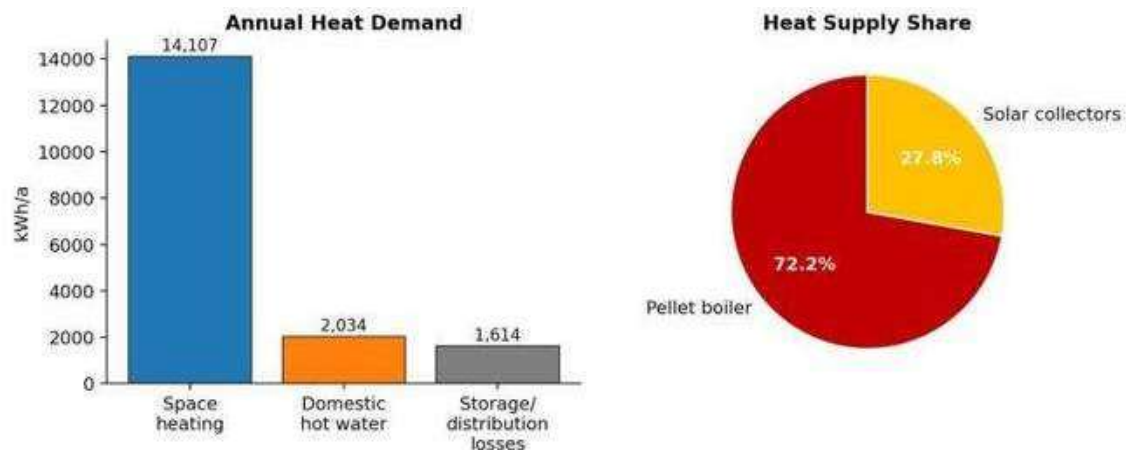


Figure 6. Annual heat demand breakdown and heat-supply share between the pellet boiler and solar collectors

From an economic perspective and based on the exchange rate of 1 EUR to Rp. 18,000, the system requires 2.6 tons of pellets annually. This results in a fuel cost of approximately Rp. 11,538,000. Additionally, there is an estimated power requirement of 7,000 kWh per year, which adds about Rp. 32,004,000 to the total. Therefore, the overall annual energy cost amounts to Rp. 43,542,000 (Kuptz et al., 2022).

The estimated capital cost for the primary components of heat generation and distribution in Table 4 is around Rp. 434,988,000. This aligns with typical investment levels reported for pellet-solar combination systems in single-family homes, where lower fuel costs than oil or gas heating help offset the higher initial expenses over the system's lifetime (Allahseh et al., 2025).

Trojanowski et al. (2022) report that the total emissions from the pellet boiler and grid electricity amount to 4,283 kg of CO₂ per year. This figure includes 3,745 kg per year from energy based on the 2015 German grid factor of 535 g CO₂ per kWh, and 538 kg per year from the combustion of pellets at a rate of 42 g CO₂ per kWh. Although electricity accounts for a smaller share of total final energy, its emissions are significantly higher due to a higher specific CO₂ factor than biomass burning. This finding aligns with the relative primary energy factors in the EnEV calculations, which are 0.2 for wood pellets and 1.8 for electricity, as noted by Attia et al. (2022).

Verification of EnEV Compliance

For final verification, the real building and the EnEV reference building with the same shape are compared (Bundesministerium für Wirtschaft und Energie, 2013). Table 3 shows that the specific transmission heat loss (0.29 W/m²K) is still below the 0.40 W/m²K limit (Deutsches Institut für Normung, 2003). The reference building requires 20,068 kWh/a of primary energy and is heated by a gas condensing boiler with 80% heat-recovery ventilation and solar domestic hot water (Table 4). The proposed pellet-solar system, on the other hand, requires just 15,164 kWh/year, a decrease of about 24% (Attia et al., 2022). Therefore, the proposed system satisfies the EnEV 2014 standards without utilizing the EEWarmeG Section 7 alternative compliance path because the transmission-loss condition and the Formula 8 ($Q_{p,ist} \leq Q_{p,ref}$) criteria are met (Bundesministerium für Wirtschaft und Energie, 2013; Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit, 2015). These results are consistent with a broader body of research demonstrating that biomass-solar combination systems are an effective means of

achieving EnEV compliance, even when the building envelope alone meets, rather than surpasses, the reference standard (Allahseh et al., 2025; Attia, S., 2022). This is due to the low primary energy factor of wood pellets (0.2, compared to 1.1 for natural gas).

CONCLUSION

In accordance with the DIN EN 12831, EnEV 2014, and EEWärmeG 2014, quantitative research using a heating load calculation model—in parallel with economic and ecological aspects—has demonstrated an integrated design and evaluation of concepts for space heating, domestic hot water supply, and ventilation design for thermal comfort in a residential house in Waghete, Indonesia. The design heating load of 6,560 W remains well below the EnEV limit of 0.40 W/m²K, with a specific heat loss through transmission of 0.29 W/m²K. Underfloor heating and panel radiators in the bathroom and shower room are deemed sufficient to meet the heating demand per room at supply/return temperatures of 35/30 °C. A wood pellet-fired boiler and a 9.4 m² flat-plate solar collector meet the annual heating demand of 17,756 kWh/a. Meanwhile, the solar collectors contribute 27.8% of the total heating demand, exceeding the 15% minimum threshold set by EEWärmeG, with annual energy costs of Rp.43,542,000 and CO₂ emissions of 4,283 kg/a. The primary energy demand is 15,164 kWh/year, approximately 24% lower than the EnEV benchmark. This means that this calculation model is fully compliant with the regulations. These findings demonstrate that an integrated system combining wood pellets and solar collectors with a low-temperature floor heating system is technically feasible and meets regulatory requirements for decarbonizing residential heating in temperate climates such as those in Waghete. Sensitivity analyses regarding fluctuations in pellet and electricity prices, dynamic (hourly) simulations to confirm the results of DIN EN 12831 under steady-state and transient conditions, along with comparisons to other renewable heat sources—such as air-source or ground-source heat pumps—should be included in future research to expand the creativity of applied design models.

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