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Heuristic Approach for Net-Zero Energy Residential Buildings in Arid Region Using Dual Renewable Energy Sources

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Abstract: Optimizing a net-zero energy (NZE) residential building using what renewable energy resources are available in desert environments and budgeted within the limits of a governmental construction project is proving to be increasingly challenging for many countries, including the Kingdom of Saudi Arabia (KSA). Buildings in such regions encounter significantly high annual energy consumption rates, especially in the cooling capacity across a project's life cycle, which in turn impacts the investment value. Therefore, this study presents a heuristic approach that aimed to examine the feasibility of NZE residential buildings in the KSA using an arid campus case study within the period of 2021–2022 based on the dual renewable energy sources of a geothermal heat pump (GHP), which served as a cooling system, and photovoltaic thermal collectors (PVT) serving as a power generation system. This study adopted a numerical technical assessment in the case study, using HAP software to analyze heating/cooling systems, and PVsyst V7.1.0 software for the variable simulation of solar photovoltaic power systems. This heuristic approach, through two assessment stages, achieved significant outcomes for a sustainable bottom-line, and provide a practical approach for achieving an NZE residential building in the King Faisal University (KFU) case study, as well as a reduction in energy consumption as well as the maintenance cost, which has a positive consequence on the payback period. Our study's results have implications for both sustainable and green buildings with similar characteristics to those we investigated, and our results could be used to develop installation guidelines for renewable energy systems. Furthermore, our results can provide decision makers with a basis for retrofitting existing buildings to enhance their energy efficiency, increase investment value, as well as prevent the indiscriminate installation of renewable energy sources to merely increase the renewable energy installation rate.

Keywords: net zero energy; geothermal energy; solar systems; sustainable building; green building; arid region

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1. Introduction

Sustainable buildings and energy have become the international objective of policymakers and an integral part of sustainable development [1]. Energy systems are the basis of national development, especially in urban areas, which collectively house 55% of the world's population, a proportion that is expected to increase to 68% by 2050 [2,3]. Non-renewable sources such as oil and gas encompass 80% of energy generation, though they are the major source of carbon dioxide emissions, which is a challenging issue which all of humanity faces [4]. A building's energy usage is thus directly related to the two global issues of energy shortage and environmental degradation [5,6]. Buildings consume

30% to 40% of the yearly primary energy in developed countries, and approximately 15% to 25% in developing countries [7]. The reason for 11% of global greenhouse gases (GHG) emissions and 28% of the carbon emitted globally is combined emissions from the building sector [8]. A reduction in energy usage in building construction would support efforts to address these global problems. Therefore, continuing to optimize energy use in buildings through improvements in building design and their energy systems is a matter of increasing concern for scholars as well as policymakers [9,10]. Residential and commercial buildings in the world consume about 50% to 65% of total energy and simultaneously contribute to 60% of carbon dioxide emissions, increasing the cost of energy bills [11]. Many countries have updated their laws, policies, and regulations to improve energy consumption, fulfill 'Sustainable Development Goal (SDG) 7′ on sustainable energy, and mitigate the risks that arise from the overuse of energy [12,13].

The KSA is classified as an arid climate and ranks among the top ten countries in the world for both the highest energy consumption per capita and for CO_2 emissions [12,14]. The government of the KSA planned an investment of USD 200 billion by 2030 to generate 200 gigawatts of energy using various types of photovoltaic (PV) solar power plants [15]. Despite the KSA being one of the largest oil-producing countries worldwide, as this is its primary energy source, the government have developed a plan to develop modern solutions to reduce overdependence on petroleum and instead use energy alternatives such as solar and wind to drive development in the Kingdom and fulfil its 2030 Vision [16,17].

The energy consumption profile in the KSA is ascending: electricity consumption data reached about 288,656,429.738 MWh in 2017, which increased to 289,929,150.000 MWh in 2018 [18]. Buildings consumed around 80% of Saudi Arabian electricity per day, with residential buildings consuming 50% of the total electricity consumption, of which air conditioning (AC) systems formed 50% of a building's electricity consumption [19]. The KSA contains five climate regions with high cooling demands for residential energy consumption between 40% and 71% [20], which can consume more than 4000 kW/h per month [21]. The KSA is now considering charging electricity customers cost-reflective rates, with newly revised tariffs [22]. The total renewable energy resources in the KSA amounted to 142 MW in 2018, and comprise wind energy at 3 MW; solar energy at 139 MW (of which solar photovoltaic was 89 MW, and concentrated solar power was 50 MW); and zero MW across hydropower, pure pumped storage, marine energy, offshore wind energy, bioenergy, solid biofuels and renewable waste, bagasse, renewable municipal waste, liquid biofuels, biogas, and geothermal energy [23,24]. The National Renewable Energy Program is an initiative strategy of the Saudi Vision 2030 and the National Transformation Program, with aims including the production of 200 gigawatts by 2030 [25]. Optimizing construction because of the climate impact and the need to reach zero carbon emissions requires optimizing energy efficiency, and moving to renewable energy is a crucial step in improving building efficiency. Thus, policymakers and regulators significantly support net-zero carbon buildings [25,26].

1.1. Net-Zero Energy Concept

Net-zero energy buildings (NZEBs) entail the employment of both passive and active measures [27]. The goals of NZEBs include zero energy costs, net-zero energy, zero energy emissions, nearly net-zero energy, and zero carbon. The common definitions of these are as follows. (1) Net-zero site energy when tracked at the site: the building generates at least as much energy as it consumes per year; (2) net-zero source energy when tracked at the source: the building generates at least as much primary energy as it consumes per year; (3) net-zero energy costs: the building's owner(s) recoup the same money they paid to the utility company throughout the year; and (4) net-zero energy emissions: the emissions-free transportation of renewable energy from emissions-producing energy sources to the building itself [28–30].

Principles for designing residential NZEBs include comfort and functional design; an airtight building enclosure; controlled ventilation; incorporating insulation to exceed energy code requirements; water and moisture movement control; size on-site renewables; building orientation to maximize renewable energy production; efficient mechanical equipment; efficient appliances, lighting fixtures, and plumbing; and the prediction of total energy movement by modeling process [31]. The common NZEB principles and features generally applied in energy include connecting to energy infrastructures and NZEBs exhibiting a significantly lower energy demand through energy-efficient measures. NZEBs generate energy from renewable energy sources [32].

The benefits of residential NZEBs include economic issues, environmental issues, and social issues. The economic issues of residential NZEBs are related to a reduction in energy bills, budget flexibility, a higher resale value in the construction industry over the whole system life cycle, energy consumption, and maintenance costs [33]. The environmental issues of residential NZEBs are related to indoor air quality, superior insulation and being airtight to reduce winter heat losses and improve summer heat gain, comfortable living space temperatures, adapted home orientation, isolation from outdoor noise, and minimizing the ecological footprint generated though greenhouse gas emissions [34]. Social issues include involving people in decision-making, proud feelings, being completely aware of maintenance details, and engaging the team and the stakeholders [35].

The residential NZEBs design principles include airtight building enclosure, controlled ventilation, insulation that exceeds the present energy code requirements, water and moisture movement controls, maximizing renewable energy production, efficient mechanical equipment, efficient lighting, plumbing fixtures and appliances, energy modeling, size on-site renewables, energy efficiency improvements, and auditing measurement reports [36]. The effective design of residential NZEBs includes (1) 3D building energy simulation software for the building shape [37], (2) using internal and external passive construction materials [36,37], and (3) using active construction buildings materials and systems which can include energy-efficient renewable energy sources such as a wind turbine, a geothermal heat pump (GHP), building-integrated photovoltaic systems (BIPV, BIPVT) in facades and rooftop, biofuels, and biomass [38–41]. Internal and external passive construction materials include (a) energy-efficient appliances and fixtures in lighting use and heating/cooling systems [39,40] and (b) using energy-efficient and high-performance thermal insulation materials in external project envelopes with a high overall R and U value, super-insulated doors and windows, and air changes per hour (ACH) [39,40]. The orientation of the site, the cost, and energy-efficient water heating are the essential factors for energy-efficient renewable energy [41–43].

There is an increasing worldwide interest in net-zero energy buildings, especially in residential NZEBs. These buildings aim to reduce emissions and the average energy consumption in buildings to obtain passive and active building levels [44]. The United Kingdom was the first country to build residential NZEBs on a large scale, with the goal of producing zero-carbon homes by 2016, as stated in the Mission Zero Independent Review of Net Zero 2022 [45]. The European Union parliament has introduced a directive regulating that all new buildings constructed, starting in January 2021, should be nearly zero-energy buildings, as stated in the Energy Performance of Buildings Directive 2010/31/EU and the Energy Efficiency Directive 2012/27/EU [46]. France has set ambitious targets for building energy-positive houses by 2020, as stated in the International Energy Agency, 2016 [47]. The U.S. Department of Energy (DOE) has targeted marketable zero-energy homes in 2020 and commercial zero-energy buildings in 2025, as stated in the Building Technologies Program BT 2008-2012 [48]. California will require all new residences to be net-zero by 2020 and all commercial buildings by 2030, as stated in the Building Technologies Program BT 2008-2012 [49]. The American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) has set a goal of market-viable residential NZEBs by 2030, as stated in the ASHRAE vision 2030 webpage in 2017 ashrae.org/vision 2030 [33,49]. Nine other countries (Australia, Brazil, Canada, France, Germany, India, the Netherlands, South Africa, and Sweden) have committed to planning net-zero carbon certification systems, tracking targets on pilot projects, and training the sector towards net-zero carbon in residential and non-residential units [34,50]. There are many approaches to realizing residential NZEBs, either through a minimized building energy demand (via improved building designs and/or occupant behaviors) or increasing renewable energy generation. There is a lack of systematic literature reviews focused on recent progress in residential NZEBs [32,49]. In the KSA, the renewable energy percentage of using solar energy in residential buildings is around 1.6% [50,51].

This study examines the applicability of net-zero energy in residential buildings located in an arid zone of the KSA with a purpose of converting the traditional applications of energy needs designs to NZEBs. This study could be considered a pioneer in the design of clean energy sources for local and private residential communities located in arid zone districts, which contribute to the achievement of a high value in real estate investment. The study adopted a clean environmental dual renewable system that includes geothermal heat pump (GHP) energy- and building-integrated thermal photovoltaic (BIPVT) modules. The study used two specific software in energy simulation to investigate the results as well as to build the heuristic approach as the special new technical calculations to be applied at King Faisal University (KFU) residential community, which could be applicable to other residential areas in arid zone countries. The study evaluated specific technical calculations to achieve the essential target in the design of NZEBs inside the residential community. This study supports decision makers in real estate investment applications to add high value to the housing market in the KSA as an arid zone country. The essential study questions are: to what extent does the geothermal and solar BIPVT as a renewable energy approach conserve energy consumption in arid residential communities? What are the geothermal heat pump specifications suitable for an energy conservation approach in an arid residential community? What system calculation details per square meter of geothermal heat pump and BIPVT system can support the residential construction project to achieve net-zero energy?

1.2. Dual Renewable Energy System Integration

Achieving residential NZEBs requires high energy efficiency systems, e.g., a cooling system to reduce power loads, and then the implementation of renewable energy sources to balance the energy consumption [52,53]. Renewable energy sources include solar, wind, geothermal, and biomass CHP (combined heat and power) as they all can be converted into electricity [54–56]. Renewable energy resources, especially solar PV, solar thermal, geothermal, and biomass, can be utilized for on-site power generation [57]. The most compatible and applicable active renewable system for residential buildings is using building-integrated photovoltaic thermal modules BIPVT in facades and rooftops for generating the required energy power and a geothermal heat pump (GHP) as a clean energy and environmentally friendly alternative system in heating/cooling systems [58].

On-site solar PV systems currently represent the dominant renewable energy technology. The two on/off-grid options included (1) photovoltaic and (2) micro combined heat and power [31,59]. Solar energy can be harnessed in many ways, including PV, solar thermal, and combined PV and thermal (PV/T). BIPV is another subset of on-site PV that entails using PV modules as exterior building features instead of conventional construction materials, replacing the outer surfaces of roofs, façades, balconies, and walls. BIPV can also reduce the building loads for space cooling or heating through the shading effect. Solar energy can also be harnessed by colors and shapes, as illustrated in Figure 1 [60–62]. All solar PV (PV, BIPV, and BIPVT) modules are of tempered glass, which requires minimal maintenance, has a productive life of about 25 years, and requires only a small amount of cleaning from smog, dust, or dirt [35,63]. A net metering policy allows solar customers to send unused electricity back to the grid for electricity bill credits [64,65].

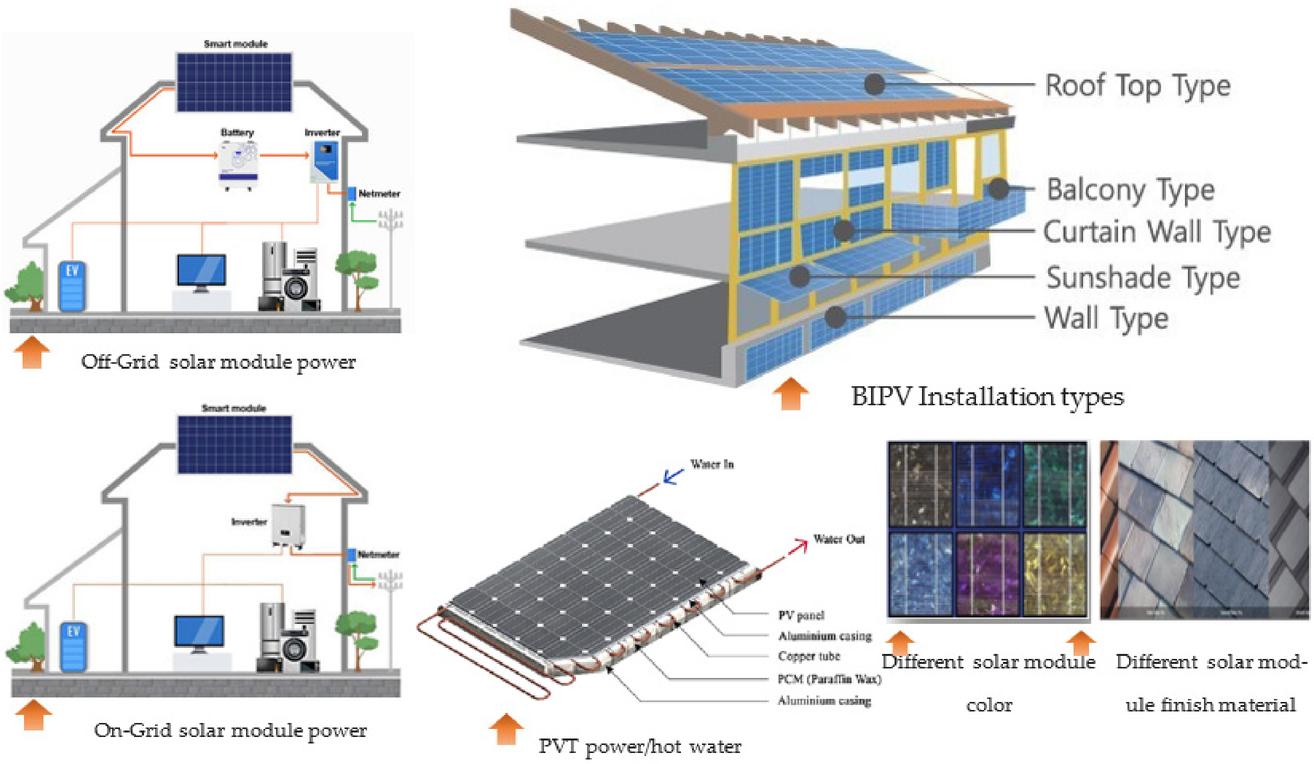
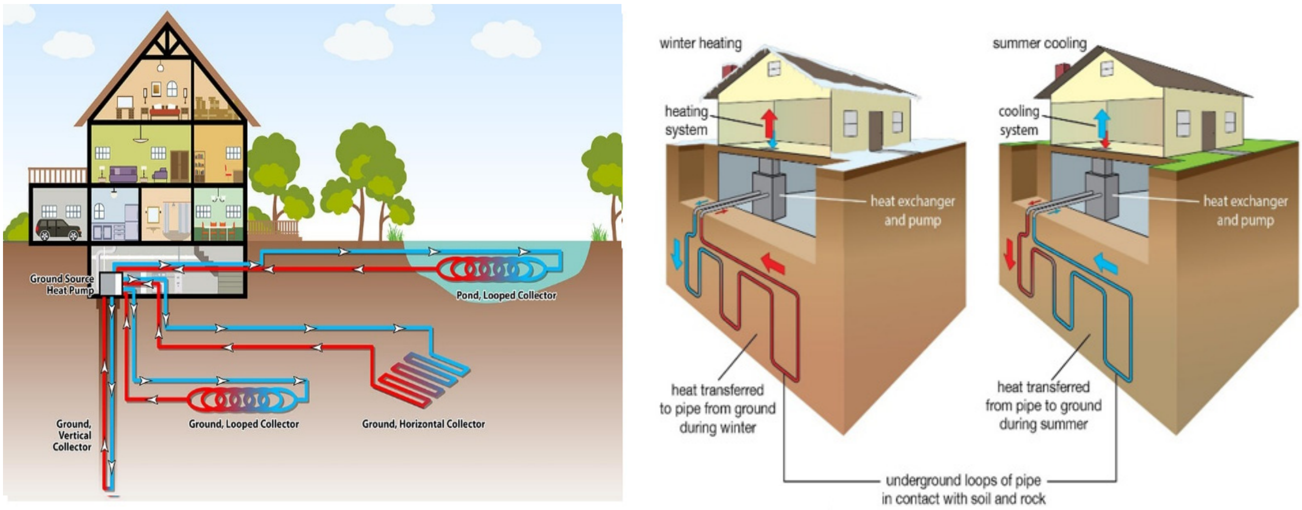


Figure 1. Various solar energy types and technologies for residential NZEBs.

Global heat delivery grew exponentially to 600 PJ in 2020. GHP is the fastest-growing segment in geothermal technology and is one of the fastest-growing applications of renewable energy technologies worldwide [66]. The energy consumption of HVAC has remained the target of building energy and holds the largest share of up to 53% of energy usage in all sorts of residential, commercial, or industrial-use buildings in urban as well as rural areas [67]. A geothermal heat pump (GHP) is a renewable energy in construction projects and can be operated as an energy-efficient cooling and heating system to meet cooling and heating requirements in residential projects [67,68].

GHP systems are the spearhead of geothermal energy that utilize the heat content of the so-called shallow resources described as the top 400 m of the subsurface, which is warmer in winter and colder in summer than outside air; therefore, it provides heating in winter and cooling in summer with GHP systems [69]. Geothermal technology allows for the use of ground heat exchangers (GHEs) that are buried underground for energy exchange with the surrounding soil via air or water due to the thermal inertia of the soil, resulting in a stable temperature of soil throughout the year. In summer, the soil beneath the ground has a lower temperature than that of the outdoor air. Similarly, in winter, the temperature of the soil is higher than ambient air [70]. GHPs represent the most promising technology for reducing carbon emissions in the building thermal sector, and the GHP systems market is predicted to expand at an annual rate of 13.1% between 2014 and 2020 [71]. There are four types of geothermal heat pumps (GHPs): water-to-air, water-to-water, ground-coupled, and groundwater heat pumps [72]. The ground-coupled heat pump system is a closed-loop coupled with a heat exchanger in the form of boreholes in the ground [73,74]. Figure 2 illustrates geothermal heat pump types and concepts.



Geothermal heat pump types

Geothermal heat pump method in summer and winter

Figure 2. Residential geothermal heat pump types and technique.

Geothermal heat pumps (GHPs) in residential construction projects have specific standards: a life cycle operation (LCO) of 25 to 50+ years, an energy efficiency ratio (EER) ranging from 10.6 to 30, and a coefficient of performance (COP) range from 2.4 to 5.0 [75,76]. Factors that affect the size of geothermal heat pumps (GHPs) depend on home size, local geology and soil, cooling and heating needs, land availability, and local incentives [77]. Geothermal heat pumps (GHPs) save from 20% to 60% annually, and are classified, as compared to other HVAC systems, as systems with low operational costs, high capital costs, and a higher energy performance [78]. Geothermal heat pumps' advantages include 25–50% less electricity than conventional HVAC cooling and heating systems, less noise, a longer lifecycle, they are environmentally friendly, durable, and have a high efficiency, which make them suitable for HVAC systems. Moreover, they require little maintenance and are not affected by outside air temperature [77,79]. In the case of geothermal heat pumps (GHPs), the financial cost breakdown elements include the installed parts and labor, net cost with tax, incentives, estimated monthly savings, simple ROI, simple payback (years), payment at 6% in the mortgage, change monthly, and cash flow [72,74]. GHP technology is one of the fastest growing applications of renewable energy technologies worldwide, and it is definitely the fastest growing segment in geothermal technology. Its capacity growth rate (in GWth) from 1995 to 2010 was 17.4%, and from 2010 to 2020 it was 11.0%. The majority of uses was in heating processes [73]. The GHPs active role in enabling NZEB includes the employment of GSHPs for space heating and cooling, which allows for lower building energy consumption expenses [74,76]. The analysis of the dual-energy systems' impact requires more studies for the distributed dispatch of integrated electricity–heat systems with a variable mass flow, and how a heat operation strategy with a variable flow and variable temperature (VF-VT) enhances flexibility and optimality [75].

2. Research Methodology

Net-zero energy residential buildings (NZEBs) in arid environments, especially public projects, are of a high concern in sustainability development visions. This study builds a heuristic approach to develop installation guidelines for residential NZEBs and provides the basis for decision-making to apply residential NZEBs as pioneer examples in arid areas. The study selected one villa with a plot area of 250 m^2 out of 335 villas which had been built with the same design in phase one of the KFU (King Faisal University), the KSA residential campus case study to which we were to apply the study to.

The heuristic approach is built through two stages. The first stage of the heuristic approach is an energy baseline analysis and calculations for the selected villa in the case study according to the as-built calculations and analysis document of all energy consumption for the selected villa from phase one, which is the built project of the case study, especially concerning the calculation of the cooling energy capacity of the HVAC package system using technical and financial data, geospatial conditions, and energy calculation data within 2020–2022 [53,76]. The second stage of the heuristic approach is a technical and numerical energy assessment based on both dual renewable systems which include a geothermal heat pump (GHP) and thermal photovoltaic (PVT) as NZE residential building sources in the new construction for phase two of the same case study. This stage was conducted to obtain two aspects. The first aspect is the calculation of the energy capacity of the geothermal heat pump (GHP) first resource of NZE residential buildings, which will be operated as a cooling system in the case study to form technical and numerical comparisons with the cooling energy capacity calculation of the HVAC package system extracted from the first stage to explore the energy reduction value. The second aspect is a technical calculation analysis for the thermal photovoltaic (PVT) second resource of NZE residential buildings, which will be operated as power generation to cover the entire demand of all the energy needed for the new construction in phase two in the case study after calculating the energy reduction from the first aspect.

The two stages used two software: Hourly Analysis Program (HAP) software and PVsyst V7.1.0 software. HAP software was used for existing HVAC systems as the analysis of heating/cooling systems, designing and sizing system components, energy analysis, comparing energy consumption and operating costs of design, and supporting alternatives for green building design HVAC systems accepted by the U.S. Green Building Council for its LEED™ (Leadership in Energy and Environmental Design) Rating System, and supported by format (EPW = EnergyPlus EPW format. IWC, ASHRAE IWEC, CSV, ASHRAE IWEC2.TM2, USA TMY2, CSV, and USA TMY3) [76].

PVsyst V7.1.0 software was used for designing, data analysis, and sizing system components for Solar Systems PC software package, the sizing of complete PV systems, performing different system simulation runs and comparing them, specifying more detailed parameters, and analyzing fine effects such as thermal behavior, wiring, module quality, mismatch and incidence angle losses, horizon (far shading), or partial shadings of near objects on the array. The results include several dozens of simulation variables, which may be displayed in monthly, daily, or hourly values, and may be even transferred to other software [77]. The main data outputs are annual PV production (MW), the specific PV production (kWh/kWp year), and the performance factor. The study compared technically the results extracted from the two stages to verify and confirm the feasibility of applying the dual renewable system to achieve NZE residential buildings in the new phase two of the case study. The NZE residential building of the heuristic approach built based on dual renewable energy in two active systems includes the following:

1. The first active renewable energy system focuses on energy saving by replacing the existing package cooling system built in phase one of the case study by applying a geothermal heat pump (GHP) as a complete cooling system in the new phase two of the case study by using HAP software to study the technical influences in an air system sizing summary from the as-built HVAC package system; the design of zone sizing for a ground heat pump; and the use of specialist companies in this field to support the technical comparison with accurate and applicable data. Appendix A illustrates design with HAP software for the zone sizing summary of a ground heat pump. Appendix B illustrates the ground heat pump's specifications, figure, and price. Appendix C illustrates the water pump's specifications, figure, and price. The temperature remains constant throughout the year, below 30 ft (9.14 m) at 82 F (27.77 °C), as illustrated in Appendix D for the nearest area for ground temperatures in Riadh city. The data and information are extracted from reliable references, the supplier, and specialist designer that include available price and technical data such as zone sizing data, terminal unit sizing data—cooling, terminal unit sizing data—heating, fan, ventilation, space loads, and airflows. The terminal unit sizing data for

cooling analysis include the total coil load (kW) with 75.8, sens coil load (kW) with 59.3, coil entering DB/WB (°C) with 26.3/19.5, water flow 8.0 °K (L/s), and time of peak load with Aug. 1500.

2. The second active renewable energy system focuses on applying an analysis to PV/T technologies on the rooftop in the case study to achieve significant results in NZE residential buildings. The capacity of applying PV/T technologies is calculated based on the entire demand of the energy needed for the villa area in the new phase two of the case study, which includes the proposed ground heat pump (GHP) for cooling, power, lighting, and others. The analysis illustrates the technical data designed with PVsyst V7.1.0 software and the distribution of solar modules in this area, the project system, and the results in summary, as well as an array of the PVT modules on the roof. The roof area is about 250 m^2, including 81 modules (panels) with 460 W, 30 kWp, and 188 kW/day for 6 h of operation, 68,703 kW/year, a 6-year payback, 743 gCO_2/kWh, SAR 144,000 system cost, and 22,700 SAR/year saving according to a local tariff (0.33 SR). Appendix E illustrates the project summary, output power distribution, cumulative cash flow, and CO_2 emission from PVsyst V7.1.0 software for 182 m^2 PVT on the roof area.
3. The study applied energy comparison analysis in the case study between the existing system and the proposed dual renewable system focusing on NZE residential buildings' technical and economic feasibility in arid areas, energy saving, sustainability, cost impacts, and other technical influences using HAP software, PVsyst V7.1.0 software, and other software based on the manufacturers' technology, which automatically export technical data sheet calculations, including occupied area (M^2), input power (kW), energy reduction (%), airflow (M^3/h), cost (USD), noise (dB), and CO_2 (gCO_2/kWh). Figure 3 illustrates the flowchart of the study method.

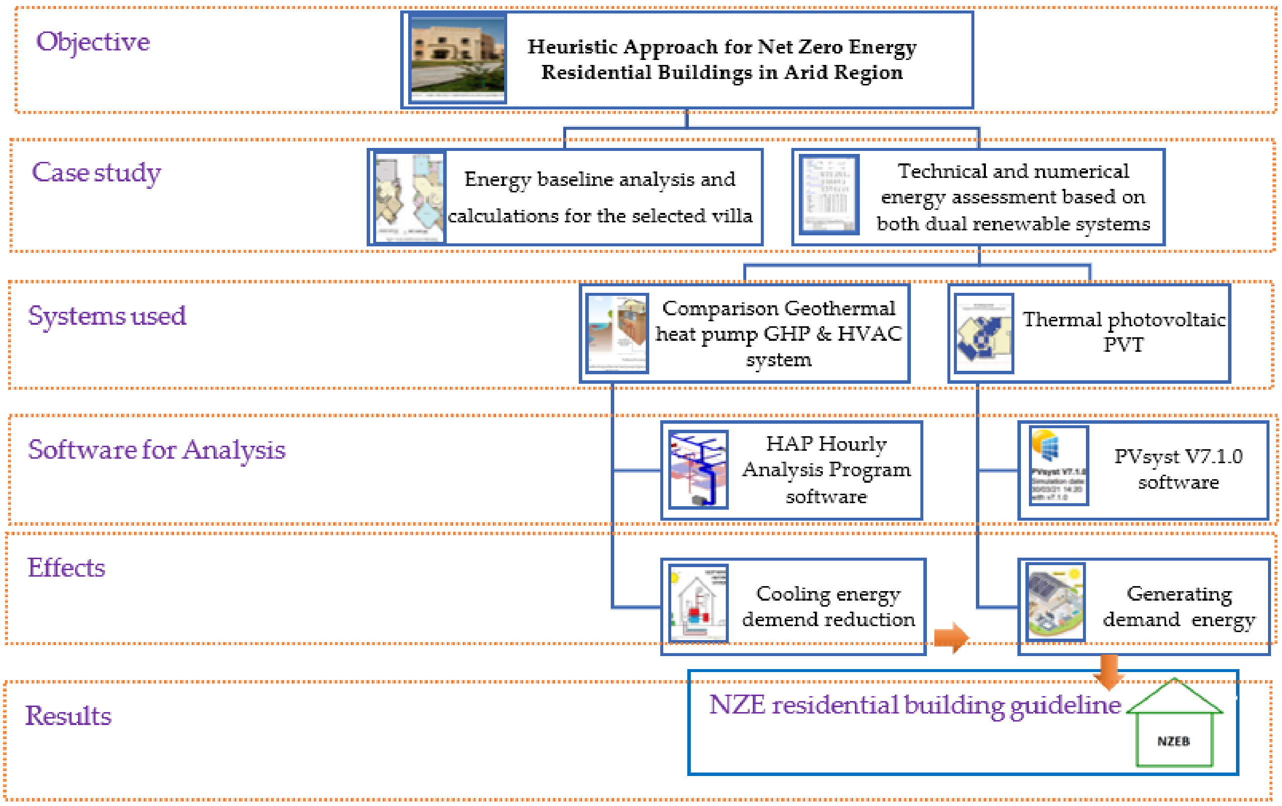


Figure 3. The study method flowchart.

To support the findings of applying the heuristic approach, the assessment results for the heuristic approach proved the feasibility of applying the proposed dual renewable energy system to achieve NZEB systems in the new phase two of the case study in the KFU residential campus located in the KSA as a residential campus in the arid zone.

The Case Study

The residential area within KFU, located in the eastern province and as an example of the arid region inside the KSA, constitutes about 1,300,000 m^2, including the infrastructure and the general location, with a rate of 40% of the University's total area, dedicated to University faculty members. The total number reaches about 1130 housing units of villas and apartments units (residential). The total number of villas is about 562, and the built area of a single villa is approximately 597 m^2 on three floors. The University is carrying out a study to increase the number of villas and apartments to suit the increasing appointment of faculty members working at the University. The villa buildings consist of the following features [75]:

- The building consists of 1 reception, 2 living rooms, 5 bedrooms, 6 bathrooms, 2 kitchens, 1 dining room, 1 laundry room, 2 main entrances, 1 room with a 10 m^2 skylight, and a roof area. Figure 4 illustrates the location of King Faisal University and the residential area, and Figure 5 illustrates the ground and first-floor plans.
- The external walls area is 984 m^2, which consists of double-wall layers; one wall has a precast 12 cm thickness with an area of 938 m^2, and the second wall is of bricks of a 12 cm thickness with an area of 536 m^2. Between both the walls is a polystyrene insulation layer with a 12 cm thickness with area of 536 m^2. The R-value is 0.8 ($W/m^2 \cdot K$).
- The glazing area is 46 m^2 and forms around 5% of the external walls.
- The cooling/heating system is 1 package unit with a 75.8/19.5 kW cooling/heating capacity. Appendix F illustrates the schedule of packaged AC (air conditioning) units, and Appendix G illustrates the packaged AC unit cooling load calculations.
- The total required energy power load is 88.66 kWh: air conditioning makes up 39.50 kWh, lighting 12.55 kWh, power 4.68 kWh, and equipment 31.93 kWh (water heaters, laundry, exhaust fans, and kitchen equipment).
- The glazing U-value is 1.7 ($W/m^2 \cdot K$)

Figure 4. Case study residential area perspective.

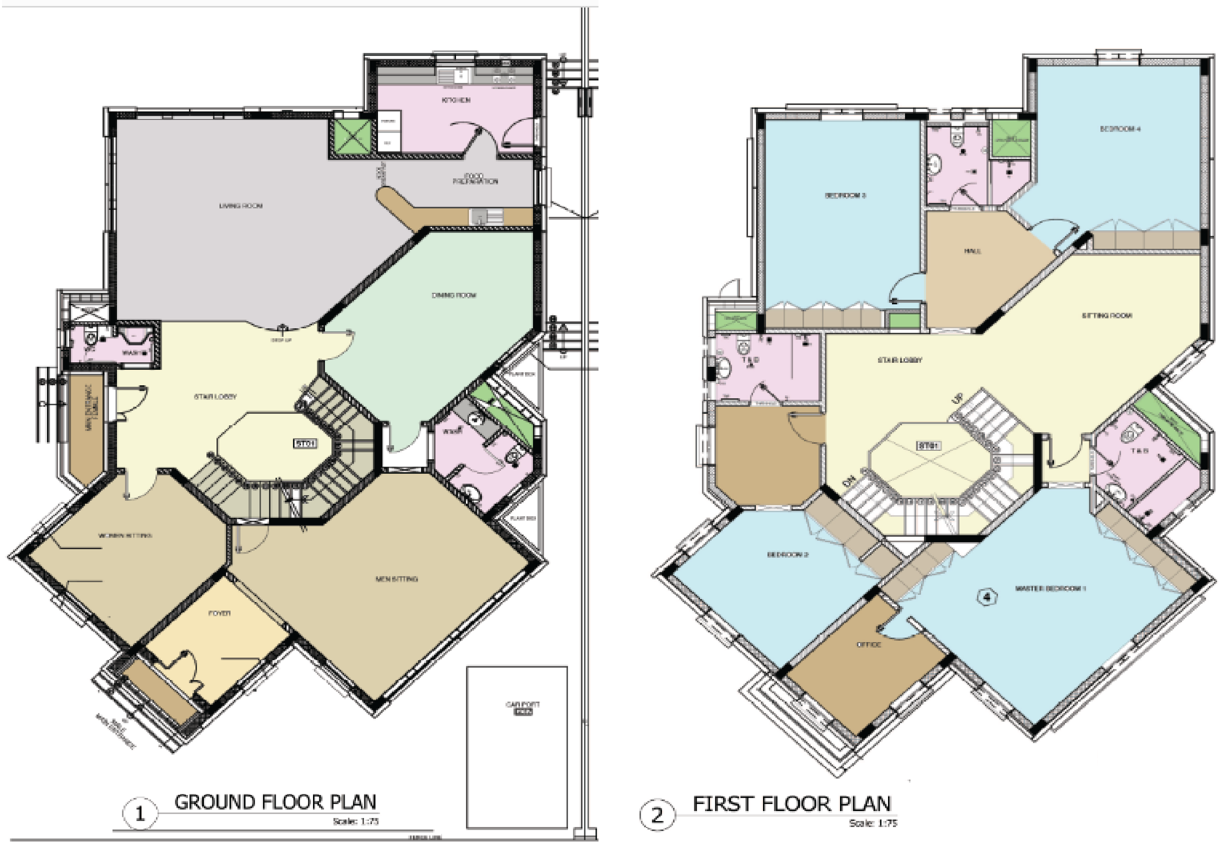


Figure 5. Ground and first-floor plans for villa building.

3. Results and Discussion

The study evaluated technical specifications and the budget cost impact on applying and operating dual renewable energy sources in the KFU villa types on the residential campus as a case study to achieve NZE residential buildings through two steps. Specific details for all energy consumption resources were conducted to examine the capacity of the photovoltaic thermal PVT and geothermal heat pump (GHP) system using HAP software for the HVAC capacity before the study and after explaining the heuristic study, and PVsyst V7.1.0 software was used for the PV/T rooftop with the 182 m^2 area of the case study.

3.1. Applying Geothermal Heat Pump System as Renewable Energy

The analysis of energy consumption based on HAP technical software data of the conventional HVAC package system installed in the first phase of the case study and as illustrated in Appendix F, which explains the schedule of packaged A/C (air conditioning) units, and Appendix G, which explains the packaged A/C units cooling load calculations, indicates that the input power is kW 39.5. The package system details include a package unit and galvanized steel ducts. Technical data for the package system include the unit type, condensation side, and evaporation side data. The unit type data include a cooling capacity of kW 75.8, a heating coil heating capacity of kW 19.5, an input power of kW 39.5, a power supply of 380 V 60 Hz, a compressor type, a hermetically sealed scroll compressor, a refrigerant medium R410A, and a refrigerant charge of kg 2 × 8.5. The condensation side data include the condenser type, Cu tube Al fin axial flow fan, drive type, direct drive, and fan power (kW 2 × 1.5. qty m^3/h 34,000.). The evaporation side data include the evaporator type, Cu tube Al fin centrifugal fan, drive type, pulley, and drive fan power (kW 5.5, airflow m^3/h 16,000). The overall dimensions of the Pa 300 unit are as follows: L mm 2878, W mm 2140, and Hmm 1964. It expresses a noise of 76 dB(A) and the unit weight is 1050 kg.

The analysis of the energy consumption based on the HAP technical software of the water ground heat pump (GHP), which was designed in this heuristic approach to replace the existing HVAC package system in the new phase two of the case study, indicates that the rated power is about 20.8 kW. The GHP uses a 1027 linear meter PVC conduit loop underground with a 10 m depth because the temperature remains constant throughout the year, i.e., below 30 ft (9.14 m) at 82 F (27.77 °C), as illustrated in Appendix D, for the nearest area in Riadh city. The system includes a ground heat pump, PVC loop, and galvanized steel ducts. The type of ground heat pump (GHP) used has the cooling capacity of 75.8 kW, and a groundwater flow of 16.3 m^3/h. The inlet temperature is 25 °C, and the outlet temperature is about 20 °C. The rated power is about 20.8 kW. The type of ground heat pump (GHP) has a heating capacity of 19.5 KW. The system operates using only one compressor. The water flow is 10 m^3/h, the inlet temperature is 10 °C, the outlet temperature is about 8.5 °C, and the power supply is 380 V/3 ph/60 Hz, R410a. The cooling capacity technical data calculations for the underground heat exchanger and length of the PVC pipes are as follows:

$$Q = m\ cp\ \Delta T,$$

where Q = the quantity of condenser heat transfer of the ground heat pump heat exchanger water in kW (kilowatt-hours) underground, and M = the heat exchanger water flowrate in L/S (liter/second)

cp (heat capacity of the water) = 4.19 KJ /kg c.

ΔT (rise in temperature of heat exchanger water in C (Celsius)) = 5 C.

M (16.3 cubic meters per hour) = 4.53 L/S.

ΔT (temperature rise) = 5 C.

Therefore,

$$Q = 4.53 \times 4.19 \times 5 = 94.903 \text{ kW} = 94{,}903 \text{ Watt}.$$

The simplified method to design the underground closed-loop uses a simple steady-state heat transfer equation:

$$Q = L\ (tg - tw)/R$$

where Q (the rate of heat transfer for the heat exchanger length in W (Watt)), L (the length of the heat exchanger (bore length) in M (meter)), tg (the temperature of the ground in C (Celsius)), tw (the average water temperature in the pipes in C (Celsius)), and R (the thermal resistance of the ground in mC/W). This equation can be rewritten as:

$$Q = L(U\ \Delta T)$$

where U (the rate of conductance for heat transfer from the circulating water to the Earth in W/C/m), ΔT ((T2 − T1)/2 − To), the difference in the average fluid temperature in the pipes ((T2 − T1)/2), and To (the earth temperature).

$$\Delta T = [(39 + (39 + 5))/2] - 27.77 = 13.73 \text{ C}.$$

where the temperature of the earth in Riyadh city in Saudi Arabia is 82 F = 27.77 C (see Appendix D). The high-temperature limit is 39C entering the water. From the above equation, (the length of the underground loop)

$$L = Q/(U\ \Delta T).$$

where U = 6.37 (W/C/m) for a 1-inch pipe size.

Therefore,

$$L = 94{,}900/(6.37 \times 13.73) = 1085 \text{ m}. \quad (1)$$

Using a ground heat pump (GHP) as a cooling system in the case study is the most economical, environmentally friendly, and technically advantageous method compared to the HVAC package system, as illustrated in Figure 6. The advantages of using a GHP instead of an HVAC package system are as follows:

- The GHP had an area of only 6 m^2, which is less than the package system, which has a 10 m^2 area.
- The GHP had an input power of 20.8 kW, which is less than the package system's power of 39.5 kW.
- The cost of the GHP system was USD 18,613, which is more than the HVAC package system costing USD 9735 (according to an accurate manufacturer's quotation), but the payback is 11.8 years for the GHP.
- The GHP achieves an energy saving of 47.34% compared to using the HVAC package system.
- The GHPs CO_2 emission reduction was 5.0 kg, and its noise reduction was 30 dB, which is less than the airflow 362 (M^3/h) and more than the HVAC package system.

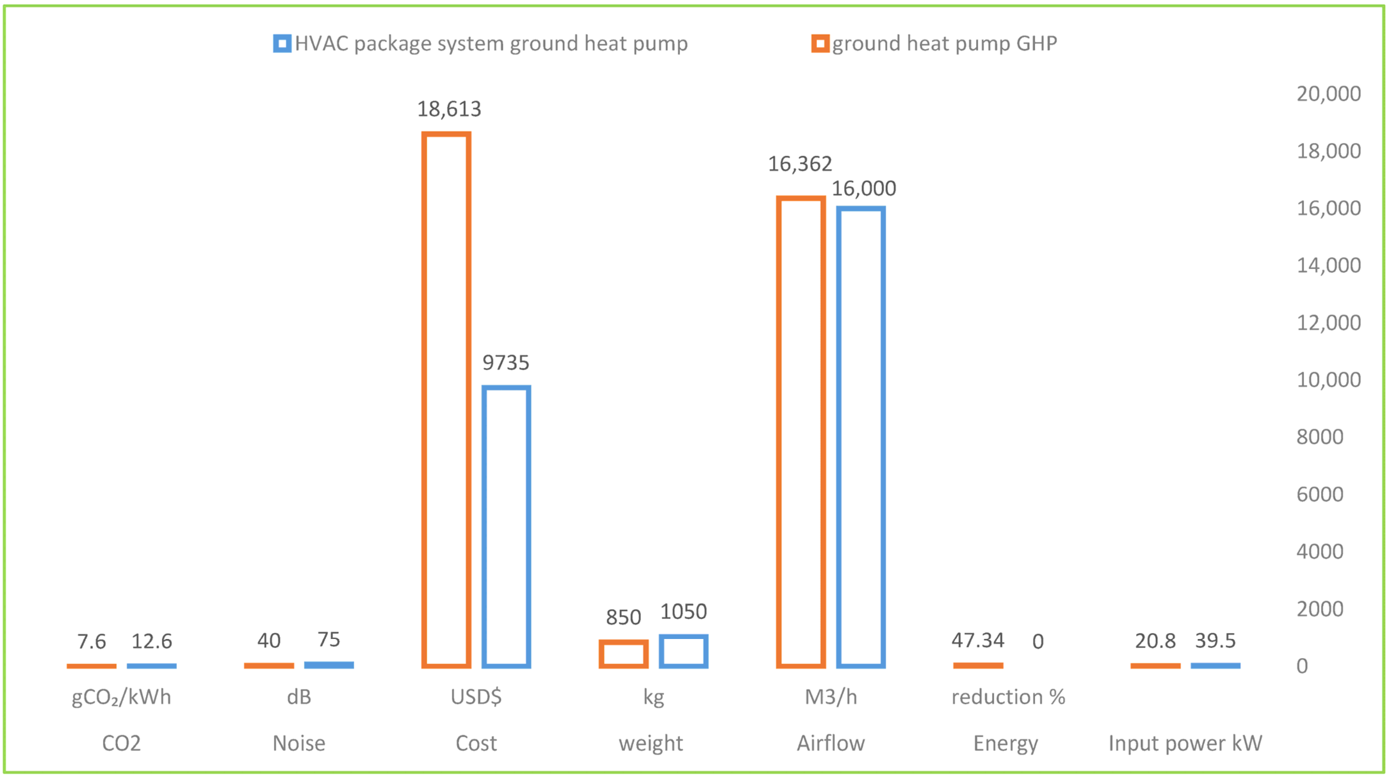


Figure 6. Data comparison for the GHP system and HVAC package system.

3.2. Applying Renewable System PVT

The study recalculated the needed energy for the selected villa in the new phase two of the case study based on the new cooling capacity after replacing the HVAC package cooling system with a geothermal heat pump (GHP) cooling system, which resulted in about an 18.7 kW reduction, as well as other power energy needed for lighting, power, and others. The study supported by energy and photovoltaic experts makes an assessment using PVsyst V7.1.0 technical software data for applying a PVT system with the complete technical data needed to achieve a heuristic approach. The simulation variant from the PVsyst V7.1.0 technical software for an 182 m^2 area in the rooftop over the selected villa roof in the case study is illustrated in Appendix E. The PV field orientation fixed planes 2 orientations tilts/azimuths was 15/0 and 4/0; the near shadings according to the strings electrical effect was 100%; users require an unlimited load (grid); the Nb. of the modules was 81 units with 460 Wp for each module; the Pnom total was 37.3 kWp; one unit inverters had a Pnom total of 36.0 k and a Wac and Pnom ratio 1.035; the results summary includes produced energy of 68,703 kWh/year, a specific production of 1844 kWh/kWp/year, and a perf. ratio (PR) of 80.94%. The simulation results indicate that PVT modules covered the needed energy for the building of the case study, which reached 85.5 kWh (air conditioning with a GHP of 20.8 kWh, lighting 7.55 kWh, and power and equipment 4.680 kWh. There was no need of the boiler for hot water because it was impeded with the PVT system. We achieved the building of an NZE residential building in the case study and proved the feasibility of the heuristic approach.

3.3. Applying the Dual Renewable Energy GHP/PVT

The study conducted a technical analysis of the dual renewable system for energy impact analysis using the Hourly Analysis Program (HAP) as the heating/cooling software, the geothermal heat pump (GHP), and PVsyst V7.1.0 software for applying the thermal photovoltaic system (PVT) to build the heuristic approach to achieve an NZE residential building in the case study area in Saudi Arabia as an example of arid zone NZE buildings. The heuristic approach NZE residential building with the dual system GHP/PVT achieved significant advantages in the triple bottom-line (TBL) of sustainability, which is a term that captures sustainability's three central pillars, such as environmental protection, social equity, and economic profitability, as well as considers a framework to measure sustainability [79]. The significant findings in environmental protection in the case study are explained in the following sentences. The dual system used renewable resources compatible with sustainability goals in energy sources, reducing pollution, because it is clean, and avoiding the depletion of resources, and is compatible with arid development areas. It achieved a noise reduction of 35 dB compared to using the HVACK package system. The GHP/PVT system achieved a CO_2 reduction of about 738 G of CO_2/ kWp (0.738 ton CO_2/kWp), reducing the heat islands from the roof, because it is a covered area. Significant findings in terms of social equity include easy accessibility for all users to maintain the dual GHP/PVT renewable system themselves, raising awareness and engaging people to participate in the environmental crisis, a source of income for families to feel happy and safe, and a source of a clean and healthy environment. The significant findings in economic profitability are explained in the following sentences. The GHP/PVT system achieved an energy saving of 17.8 kW, showing an increased saving of 47.34% in the cooling system compared to using the HVAC package system. The reduction in energy bills reached about 1600 USD/year (5290 USD/year for the GHP system compared to the HVAC package system saving of 3690 USD/year). The payback for the GHP/PVT system on average reached about 6 and 11.8 years for both compared to the package system, which has no payback. It reduced the energy cost overrun and enhanced the value of real estate investment.

4. Conclusions

This study presents a heuristic approach for the installation of a geothermal heat pump (GHP) and thermal photovoltaic (PVT) systems as dual renewable systems GHP/PVT to achieve NZE residential building in the arid campus case study of KFU. The related regulations in terms of renewable energy are enhanced inside KFUs residential building campus as an example of arid areas. The NZE residential building's technical assessment in the case study was conducted by using the HAP software and PVsyst V7.1.0 software, as well as direct communication with international manufacturers of materials and systems for the GHP/PVT. The heuristic approach considers the economic, social, and environmental feasibility of NZE residential building factors to build optimal energy generation guidelines, as well as the optimal capacity and energy efficiency.

The optimization of the heuristic approach to achieve an NZE residential building proceeded in two stages. The first stage was a reduction in the energy of the cooling system by using the HAP software through a technical and numerical assessment comparison in the case study to replace the HVAC package cooling system with a geothermal heat pump GHP cooling system, which achieved an energy saving of 17.8 kW with a 47.34% cooling capacity. In addition, a multi-purpose design was performed considering the economic, social, and environmental feasibility. The second stage is optimizing the clean energy capacity needed to achieve NZE residential buildings in the case study residential campus. This method used PVsyst V7.1.0 software for a technical feasibility energy assessment to adjust the NZE residential buildings' required energy power generation by applying the thermal photovoltaic (PVT) systems with 81 PVT modules, a 21% efficiency, and 460 Wp/module. The total Pnom (PV power (nominal at STC)) was 37.3 kWp after considering the energy saving from the GHP system, which covered all the residential villas in the selected case study area with the needed power generation of an NZE residential building. The objectives of the dual renewable system GHP/PVT used in the heuristic approach include: (1) environmental protection in the case study, including compatibility with sustainability goals in energy sources, and reducing pollution, noise, CO_2 emissions, and heat islands; (2) social equity includes easy individual accessibility and maintenance, the awareness and engagement of the people to participate in the environmental crisis, and positive moral effects; and (3) economic profitability includes a 17.8 kW energy saving with a 47.34% cooling capacity in the cooling system from using an HVAC package system, a reduction in energy bills and costs overrun, short payback, sufficient hot water per year, and the prevention of indiscriminate installation.

In the case study, an analysis was conducted on residential buildings in the KFU residential campus, which are typical energy-consuming buildings, and guidelines for installing dual renewable energy systems were presented using University campus residential buildings in Saudi Arabia as a case study in the arid zone. The results show that installing a GHP system with an energy power of 20.8 kW, 81 PVT modules with an efficiency of 21%, and a total power generation of 37.3 kW is the most efficient optimization of the heuristic approach. This study method can be used as an accurate reference and base model to facilitate decision making on the installation of renewable energy for retrofitting, increasing the energy efficiency for the existing buildings, and providing guidelines for installation based on the renewable energy systems in newly built construction projects compatible with the country's vision, policies, and electricity grid systems regulations. This study opens the gate for future studies on the NZEBs in arid zones using other renewable energy sources, such as wind, hydro, and variable parameters, e.g., natural insulation material for the building envelope, natural ventilation system, and other parameter systems and materials.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Zone Sizing Summary for Ground Heat Pump

Project Name: Staff housing building 10/15/2020
Prepared by: AAA 09:55AM

Air System Information

Air System Name .... Ground Heat Pump
Equipment Class .... TERM
Air System Type .... GSHP
Number of zones 1
Floor Area .... 472.7 m²
Location .... AL AHSA, Saudi Arabia

Sizing Calculation Information

Zone and Space Sizing Method:

Zone L/s .... Sum of space airflow rates
Space L/s .... Individual peak space loads
Calculation Months .... Jan to Dec
Sizing Data .... Calculated

Zone Sizing Data

Zone Name	Maximum Cooling Sensible (kW)	Design Air Flow (L/s)	Minimum Air Flow (L/s)	Time of Peak Load	Maximum Heating Load (kW)	Zone Floor Area (m²)	Zone L/(s-m²)
Zone 1	50.6	4545	4545	Aug 1500	13.7	472.7	9.62

Terminal Unit Sizing Data - Cooling

Zone Name	Total Coil Load (kW)	Sens Coil Load (kW)	Coil Entering DB / WB (°C)	Coil Leaving DB / WB (°C)	Water Flow @ 8.0 °K (L/s)	Time of Peak Load
Zone 1	75.8	59.3	26.3 / 19.5	15.3 / 14.7	-	Aug 1500

Terminal Unit Sizing Data - Heating, Fan, Ventilation

Zone Name	Heating Coil Load (kW)	Heating Coil Ent/Lvg DB (°C)	Htg Coil Water Flow @11.0 °K (L/s)	Fan Design Airflow (L/s)	Fan Motor (BHP)	Fan Motor (kW)	OA Vent Design Airflow (L/s)
Zone 1	19.5	20.0 / 23.6	-	4545	0.000	0.000	367

Space Loads and Airflows

Zone Name / Space Name	Mult.	Cooling Sensible (kW)	Time of Load	Air Flow (L/s)	Heating Load (kW)	Floor Area (m²)	Space L/(s-m²)
Zone 1							
Bedroom 2	1	2.2	Aug 1500	200	0.7	20.0	10.00
Bedroom 3	1	3.2	Jul 1500	286	1.2	29.4	9.74
Bedroom 4	1	3.3	Jul 1500	292	1.2	28.1	10.39
Beside Bedroom 2	1	1.4	Aug 1500	123	0.5	9.2	13.36
Dining Room	1	3.0	Jul 1500	268	0.5	28.7	9.32
Foyer	1	1.4	Sep 1500	122	0.5	9.7	12.56
Hall	1	0.9	Jul 1500	81	0.2	10.5	7.72
Kitchen	1	2.4	Jul 1500	211	0.7	13.9	15.17
Living Room and Stair Lo	1	8.2	Jul 1500	732	1.5	100.0	7.32
Maids, Hall, laundary Ro	1	3.5	Jul 1500	315	1.3	29.1	10.81
Master Bedroom	1	4.0	Aug 1500	361	1.3	39.3	9.20
Men Sitting	1	5.5	Aug 1500	491	1.1	40.2	12.21
Office	1	1.7	Sep 1500	150	0.6	10.5	14.28
Skylight	1	2.9	Aug 1500	259	1.2	23.5	11.02
Stair Lobby (First)	1	4.5	Aug 1500	399	0.8	59.8	6.67
Women Sitting	1	2.9	Aug 1500	256	0.6	20.8	12.32

Hourly Analysis Program v4.50 Page 1 of 1

Figure A1. Design with HAP software for zone sizing summary for ground heat pump.

Appendix B

Date: Feb. 1st, 2021

Product name	Description	Unit EXW Price (USD)	Qty	Total EXW Price (USD)
Ground source heat pump	Cooling capacity: 75.8kw. Groundwater flow 16.3m3/h.The inlet temperature is 25℃ and the outlet temperature is about 20℃. Rated power is about 16.8kW. Heating capacity: 19.5kw. This can be achieved by running only 1 compressor.Heating according to water flow of 10m3/h, inlet temperature of 10℃, outlet temperature of about 8.5℃. Power supply: 380V/ 3 ph/ 60Hz, R410a.	11,613	1	11,613

Ground heat pump

Figure A2. Ground heat pump specifications, figure, and price.

Appendix C

Sr.#	Description	Qty.	U/Price	Total (SR)
1	Supply of the following: - Complete ready to install booster pump set Consists of the following: - 2 X Grundfos vertical multistage in line pump Model CR15-3, coupled with 4 KW, 3 phase, 380 volts, 60HZ, 3500 RPM Electric motors. Pumps connected through suction manifold and discharge manifold, this system is complete regarding valves, fittings Pumps are operated and protected by a DOL Control panel for 2 X 4 KW, 380 volts, Automatic and manual operation with dry running protection. Pumps and panel are assembled on a steel base frame, also 500 litters pressure tank to be supplied loose Capacity: 4.53 L/S @ 50 Meter / Pump	1 Set	26,000	26,000

Circulating water pump

Figure A3. Water pumps specifications, figure, and price.

Appendix D

State	City	GWT (F)	State/Country	City	GWT (F)	State/Country	City	GWT (F)
Alabama	Birmingham	65	South Carolina	Charleston	66	Germany	Frankfurt	52
Alabama	Mobile	70	South Carolina	Columbia	64	Germany	Hamburg	51
Alabama	Montgomery	67	South Carolina	Greenville	62	Germany	Munich	49
Alaska	Anchorage	40	South Dakota	Sioux Falls	51	Germany	Stuttgart	51
Alaska	Fairbanks	0	Tennessee	Knoxville	61	Greece	Athens	67
Arizona	Phoenix	73	Tennessee	Memphis	63	Hungary	Budapest	53
Arkansas	Little Rock	64	Tennessee	Nashville	60	Indonesia	Jakarta	83
California	Fresno	68	Texas	Austin	71	Ireland	Dublin	52
California	Los Angeles	64	Texas	Dallas	68	Israel	Jerusalem	63
California	Sacramento	67	Texas	Houston	71	Italy	Genova	60
California	San Diego	64	Texas	San Antonio	72	Italy	Milan	57
California	San Francisco	60	Utah	Salt Lake City	53	Italy	Naples	63
Colorado	Denver	52	Vermont	Burlington	46	Italy	Palermo	66
Connecticut	Hartford	51	Virginia	Norfolk	61	Italy	Rome	61
Delaware	Dover	57	Virginia	Richmond	60	Italy	Torino	58
Florida	Daytona Beach	70	Virginia	Roanoke	59	Italy	Trieste	58
Florida	Jacksonville	71	DC	Washington	57	Italy	Venice	58
Florida	Miami	78	Washington	Seattle	53	Japan	Nagoya	62
Florida	Tallahassee	69	Washington	Spokane	49	Japan	Osaka	63
Florida	Tampa	75	West Virginia	Charleston	58	Japan	Sapporo	51
Georgia	Atlanta	62	Wisconsin	La Crosse	48	Japan	Tokyo	64
Georgia	Savannah	67	Wisconsin	Milwaukee	47	Korea	Inch'on	56
Hawaii	Honolulu	79	Wyoming	Cheyenne	48	Korea	Pusan	59
Idaho	Boise	47	Alberta	Calgary	42	Korea	Seoul	57
Illinois	Chicago	51	Alberta	Edmonton	40	Kuwait	Kuwait City	80
Illinois	Springfield	56	British Columbia	Vancouver	53	Libyan Arab Jamahiriya	Tripoli	71
Indiana	Fort Wayne	53	Manitoba	Winnipeg	40	Malaysia	George Town	84
Indiana	Indianapolis	55	New Brunswick	Moncton	42	Malaysia	Kuala Lumpur	83
Iowa	Des Moines	53	Newfoundland	Saint John's	43	Mexico	Acapulco	78
Kansas	Wichita	59	Nova Scotia	Halifax	45	Mexico	Mexico City	65
Ohio	Cincinatti	57	Ontario	Ottawa	45	Mexico	Veracruz	75
Kentucky	Lexington	60	Ontario	Toronto	48	Morocco	Casablanca	66
Kentucky	Louisville	60	Prince Edward Island	Charlottetown	42	Netherlands	Amsterdam	52
Louisiana	New Orleans	70	Quebec	Montreal	46	New Zealand	Auckland	56
Louisiana	Shreveport	66	Saskatchewan	Regina	39	New Zealand	Christchurch	54
Maine	Caribou	46	Argentina	Buenos Aires	64	New Zealand	Wellington	57
Maine	Portland	48	Australia	Adelaide	64	Norway	Oslo	46
Maryland	Baltimore	57	Australia	Brisbane	72	Paraguay	Asuncion	64
Massachusetts	Boston	50	Australia	Canberra	67	Peru	Lima	70
Massachusetts	Worchester	50	Australia	Melbourne	59	Philippines	Manila	67
Michigan	Detroit	50	Australia	Perth	67	Poland	Krakow	48
Michigan	Flint	49	Australia	Sydney	67	Poland	Warsaw	49
Michigan	Grand Rapids	46	Austria	Salzburg	51	Portugal	Porto	64
Minnesota	Duluth	41	Austria	Vienna	50	Puerto Rico	San Juan	84
Minnesota	Minneapolis	47	Bahrain	Manama	80	Qatar	Doha	83
Mississippi	Jackson	67	Belgium	Brussels	52	Romania	Bucharest	54
Missouri	Kansas City	58	Bolivia	La Paz	50	Saudi Arabia	Riyadh	82
Missouri	St. Louis	58	Brazil	Belem	82	Singapore	Singapore	82
Montana	Billings	49	Brazil	Brasilia	80	Spain	Barcelona	62
Montana	Helena	47	Brazil	Recife	78	Spain	Madrid	60
Nebraska	Omaha	53	Brazil	Sao Paulo	78	Spain	Sevilla	67
Nevada	Las Vegas	69	Bulgaria	Sofia	55	Spain	Valencia	65
Nevada	Reno	50	Chile	Santiago	61	Sweden	Stockholm	47
New Hampshire	Concord	50	China	Beijing	58	Switzerland	Geneva	53
New Jersey	Trenton	55	China	Guangzhou	77	Syria	Damascus	71
New Mexico	Albuquerque	59	China	Harbin	53	Taiwan	Taipei	75
New York	Albany	50	China	Hong Kong	77	Thailand	Bangkok	85
New York	Buffalo	50	China	Shanghai	62	Tunisia	Tunis	69
New York	New York City	52	China	Shenyang	55	Turkey	Ankara	52
North Carolina	Asheville	59	Colombia	Bogota	58	Turkey	Istanbul	60
North Carolina	Charlotte	62	Cuba	Havana	77	Turkey	Izmir	64
North Carolina	Greensboro	60	Czech Republic	Prague	50	United Arab Emirates	Abu Dhabi	80
North Carolina	Raleigh	62	Denmark	Copenhagen	47	United Arab Emirates	Dubai	80
North Dakota	Bismarck	44	Ecuador	Quito	60	United Kingdom	Aberdeen	49
North Dakota	Fargo	42	Egypt	Aswan	78	United Kingdom	Belfast	51
Ohio	Cleveland	51	Egypt	Cairo	73	United Kingdom	Birmingham	52
Ohio	Columbus	55	Finland	Helsinki	47	United Kingdom	Edinburgh	50
Ohio	Dayton	50	France	Bordeaux	61	United Kingdom	Liverpool	54
Oklahoma	Oklahoma City	62	France	Lyon	57	United Kingdom	London	54
Oregon	Portland	54	France	Marseille	59	Uruguay	Montevideo	64
Pennsylvania	Harrisburg	52	France	Nantes	56	Venezuela	Caracas	78
Pennsylvania	Philadelphia	55	France	Paris	54	Vietnam	Hanoi	84
Pennsylvania	Pittsburgh	52	Germany	Berlin	52	Yugoslavia	Belgrade	55

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Figure A4. Ground temperature.

Appendix E

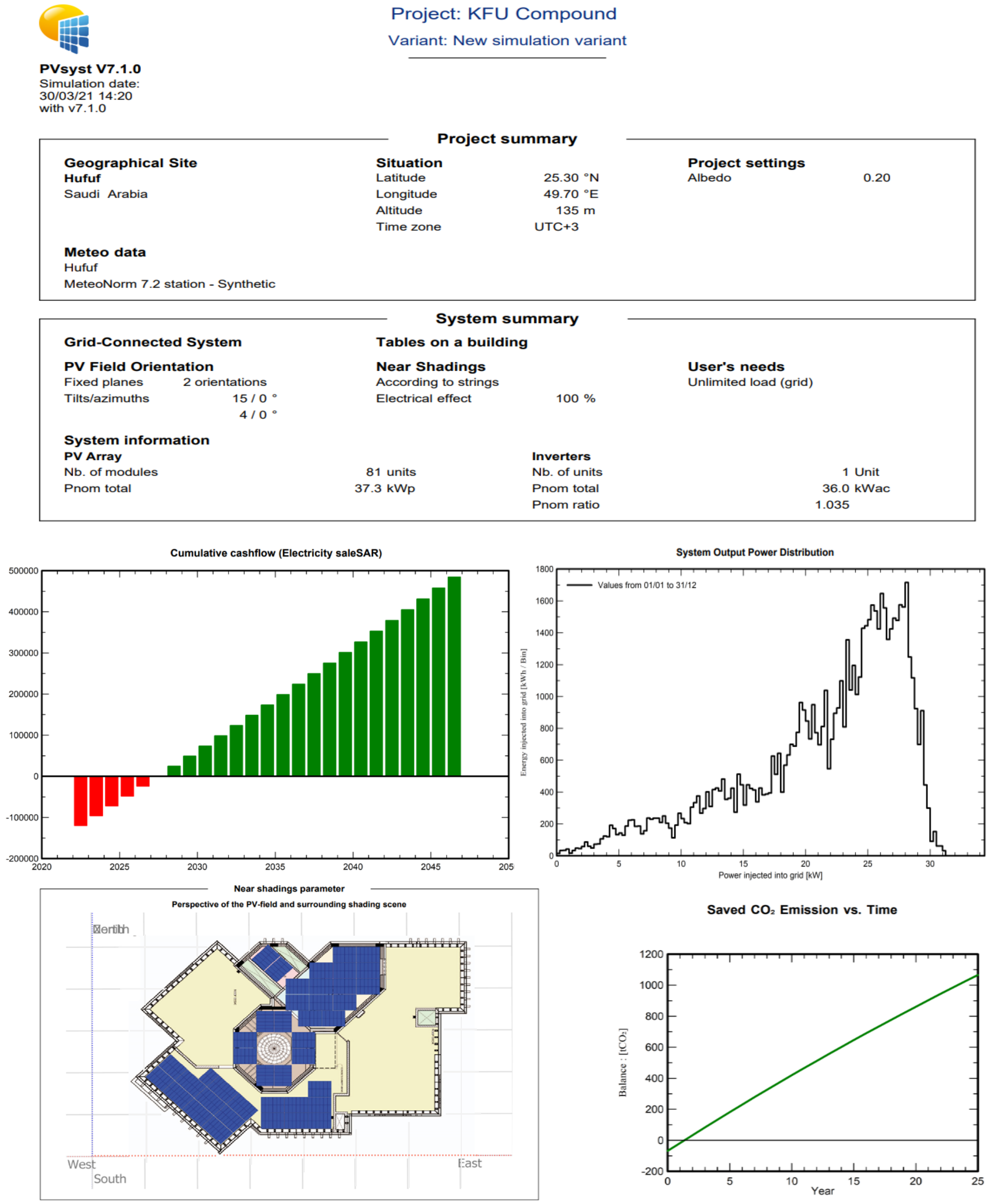

Figure A5. Project summary, output power distribution, cumulative cashflow, and CO_2 emissions from PVsyst V7.1.0 software for 181.5 m^2 PVT on roof area.

Appendix F

Table A1. Schedule of packaged A/C units.

Model No.			**WF757SA**
Cooling capacity		kW	75.8
Heat water coil heating capacity		kW	19.5
Unit input power		kW	39.5
Power supply			3P 308V 50 Hz
Compressor	type		Hermetically sealed scroll compressor
	qty		2
Refrigerant	type		R410A
Refrigerant type	Kg		2 × 10.5
Consideration side			
Condenser	type		Cu tube Al fin
Axial flow fan	qty		1
	Drive type		Direct type
	Fan motor power	kW	2 × 1.5
	Air flow	M^2/h	34,000
Evaporation side			
Evaporator	Type		Cu tube Al fin
Centrifugal fan	Qty		1
	Drive type		5.5
	Fan motor power	kW	16,000
	Air flow	M^2/h	300
	Margin blast pressure	Pa	
Overall dimension	L	mm	2878
	W	Mm	2140
	H	mm	1964
Noise		dB(A)	76
Unit weight		kg	1050

Note: 1} The unit cooling capacity and power consumption calibration condition: outdoor environment dry/wet bulb temperature 46.5/29C, evaporator inlet air dry/wet bulb temperature 26.3/19.5C.

Appendix G

Air System Sizing Summary for Packaged Rooftop System

Project Name: Staff housing building 02/01/2021
Prepared by: ZFP 02:45PM

Air System Information

Air System Name	Packaged Rooftop System		Number of zones	1	
Equipment Class	PKG ROOF		Floor Area	472.7	m²
Air System Type	SZCAV		Location	AL AHSA, Saudi Arabia	

Sizing Calculation Information

Zone and Space Sizing Method:

Zone L/s	Sum of space airflow rates	Calculation Months	Jan to Dec
Space L/s	Individual peak space loads	Sizing Data	Calculated

Central Cooling Coil Sizing Data

Total coil load	75.8	kW	Load occurs at	Aug 1500	
Sensible coil load	59.3	kW	OA DB / WB	46.5 / 29.1	°C
Coil L/s at Aug 1500	4545	L/s	Entering DB / WB	26.3 / 19.5	°C
Max block L/s	4545	L/s	Leaving DB / WB	15.3 / 14.7	°C
Sum of peak zone L/s	4545	L/s	Coil ADP	14.1	°C
Sensible heat ratio	0.783		Bypass Factor	0.100	
m²/kW	6.2		Resulting RH	56	%
W/m²	160.3		Design supply temp.	14.4	°C
Water flow @ 5.6 °K rise	N/A		Zone T-stat Check	1 of 1	OK
			Max zone temperature deviation	0.0	°K

Central Heating Coil Sizing Data

Max coil load	19.5	kW	Load occurs at	Des Htg	
Coil L/s at Des Htg	4545	L/s	W/m²	41.2	
Max coil L/s	4545	L/s	Ent. DB / Lvg DB	20.0 / 23.6	°C
Water flow @ 11.1 °K drop	N/A				

Supply Fan Sizing Data

Actual max L/s	4545	L/s	Fan motor BHP	0.00	BHP
Standard L/s	4453	L/s	Fan motor kW	0.00	kW
Actual max L/(s-m²)	9.62	L/(s-m²)	Fan static	0	Pa

Outdoor Ventilation Air Data

Design airflow L/s	367	L/s	L/s/person	4.27	L/s/person
L/(s-m²)	0.78	L/(s-m²)			

Figure A6. Packaged A/C units cooling load calculations.

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