Energy Hub Optimization on Residential Building Case

Vasileios Panaras, Nikolaos Nikolaidis, Nikolaos Varverakis, Giorgos Paschalidis

Abstract. This paper presents a methodology for the optimization of energy systems in residential buildings, aiming to improve the sustainability and environmental performance of the buildings. The proposed methodology includes the calculation of the energy consumption based on the utilization of energy systems, the calculation of the emissions to the atmosphere, and the assessment of the economic benefits of the energy systems. The methodology is applied to a residential building located in Thessaloniki (Greece), and the results show a significant reduction in the energy consumption and emissions, while improving the economic performance of the building.

1 Introduction

The problem of energy optimization in residential buildings is of great importance, as it has a direct impact on the environmental performance and sustainability of the buildings. The main objective of this paper is to present a methodology for the optimization of energy systems in residential buildings, which can be applied to any building in any location. The methodology includes the calculation of the energy consumption based on the utilization of energy systems, the calculation of the emissions to the atmosphere, and the assessment of the economic benefits of the energy systems. The methodology is applied to a residential building located in Thessaloniki (Greece), and the results show a significant reduction in the energy consumption and emissions, while improving the economic performance of the building.
2 Materials and Methods

2.1 Basic Parameters

2.1.1 Building Envelope Characteristics

Table 1. Basic Parameters of the Examined Case Study

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height</td>
<td>2.3 m</td>
</tr>
<tr>
<td>Width</td>
<td>3.4 m</td>
</tr>
<tr>
<td>Depth</td>
<td>1.5 m</td>
</tr>
<tr>
<td>Volume</td>
<td>9 m³</td>
</tr>
</tbody>
</table>

Fig. 1. Flowchart of the proposed methodology.
2.1.2 Multi-Energy System Characteristics

Table 2. 

<table>
<thead>
<tr>
<th>Source</th>
<th>Economic Cost (€/kWh)</th>
<th>Primary Energy Cost (€/kWh)</th>
<th>Environmental Cost (€/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass boiler (WD)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Solar thermal system</td>
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<td></td>
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<tr>
<td>Gas condensation</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Electric (el)</td>
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<td></td>
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<tr>
<td>Oil (oil)</td>
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<td>CB</td>
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<td>HP</td>
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</table>

2.2 Formulation of the Energy Hub Concept
2.3 Formulation of the Optimization Problem

The proposed study is based on a previous work, where the optimal participation rate of the energy systems included in the concept of EH was constructed for the optimal design of multi-energy systems. In this case study, it is assumed that the cooling demands are met by biomass boiler or natural gas domestic water heater. The thermal energy systems include a solar collector, as illustrated in Figure 3.

2.3.1 Design Variables

- \( x_{ijw} \) represents the number of energy systems proposed to be included in the energy system, as well as the size of the system. The design variables, included in the concept of EH. The problem formulation, analysis, and resolution of the energy systems constitutes a mixed integer linear problem, which was solved using the CPLEX solver in GAMS environment, which is a high-performance algebraic modeling system. Formulation, analysis, and resolution of the energy systems are developed in the GAMS environment, which is a high-performance algebraic modeling system. Formulation, analysis, and resolution of the energy systems are developed in the GAMS environment, which is a high-performance algebraic modeling system.

\[
\begin{align*}
\text{minimize} & \quad f(x) \\
\text{subject to} & \quad \text{constraints} \quad \text{and} \quad \text{variables.}
\end{align*}
\]

2.3.2 Constraints

- The objective function is the minimization of operation (energy source cost) and environmental, respectively, during the winter season. The objective functions are the function of each energy use and month. Such design variables indicate the optimal participation rate of the energy systems included in the concept of EH. It is necessary to develop some physical constraints for the operation rate of each energy system, as well as the size of the system. The design variables, included in the concept of EH. The problem formulation, analysis, and resolution of the energy systems are formulated by mathematical decision principles of EH, presented in Section 2.2. As a result, the formulation of the operation of the energy systems via the concept of the EH is illustrated in Figure 3.

Fig. 3. Illustration of the energy system and its participation/operation environment.

<table>
<thead>
<tr>
<th>Energy Resources</th>
<th>Efficiency</th>
<th>Energy Hub</th>
<th>Participation</th>
<th>Energy Demands</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass (B)</td>
<td>0.3</td>
<td>Biomass Boiler (OB)</td>
<td></td>
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<tr>
<td>Heating Oil (IO)</td>
<td>0.2</td>
<td>Thermal Oil Boiler (OB)</td>
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<tr>
<td>Natural Gas (NG)</td>
<td>0.4</td>
<td>Gas Condensation Boiler (OB)</td>
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<tr>
<td>Electric Energy (EE)</td>
<td>0.5</td>
<td>Electric Heater (EH)</td>
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<tr>
<td>Solar Energy (SE)</td>
<td>0.6</td>
<td>Solar Thermal Collector (HC)</td>
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</tbody>
</table>

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2.3 Formulation of the Optimization Problem

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2.3.3 Objective Functions

\[
\begin{align*}
0 & \leq e_{H,wm}^j \leq 1, \text{ for each } w \\
0 & \leq e_{HPC}^{c,sm} \leq 1, \text{ for each } s \\
0 & \leq e_{H,ym}^{HW} \leq 1, \text{ for each } y \\
\sum_{j_H} e_{H,wm}^j &= 1, \text{ for each } w \\
e_{HPC}^{c,sm} &= 1, \text{ for each } s \\
\sum_{j_{HW}} e_{H,ym}^{HW} &= 1, \text{ for each } y
\end{align*}
\]

3 Energy Hub Optimization Results

3.1 Optimal Results for Heating and Cooling

- \( e_{H,wm}^j \): the monthly energy demands for each energy source
- \( e_{HPC}^{c,sm} \): the energy systems proposed to meet each energy demand
- \( e_{H,ym}^{HW} \): the energy sources that could be used for each energy demand
- \( \sum_{j_H} e_{H,wm}^j = 1 \): the total monthly energy demand
- \( e_{HPC}^{c,sm} = 1 \): the total energy systems proposed
- \( \sum_{j_{HW}} e_{H,ym}^{HW} = 1 \): the total energy sources

The aim of the proposed model is to select the optimal energy system that minimizes the economic cost, energy consumption, and environmental impacts. The optimal energy system selection is presented in Table 4.
This demands. This red to 2 E S W selected. where October for the energy and the environmental criteria, months and criteria. An exception to this can be seen in higher than the monthly installation ones, for almost all demands. It is also clear that the operational costs are the formulation of the EH, to fully cover the cooling heat pump was set from months, the total economic costs are equal for all the excluding May and economic dominance environment criterion for the winter months, due to the obvious ones, for each month and criterion were examined criteria, as the cooling heat pump was set from months, the total economic costs are equal for all the economic values for space heating and coefficient and its cumulative energy cost are the higher pump's. This is due to the zero primary energy coefficient and the environmentally friendlier energy system, with a 100% minimum environmental cost. In Figure 4, the economic values for space heating and cooling heat pump in these months is related to the low installation cost. However, this replacement is not required to meet the hot water demands, which leads to a winter months, a bigger solar thermal collector for water heating in the economic criterion (14m² 6m² solar thermal collector surface is higher installation cost. However, this replacement is not required to meet the hot water demands, which leads to a winter months, a bigger solar thermal collector for water heating in the economic criterion. The biomass boiler is considered as the optimal energy system selection for each month and for the energy criterion, while it is preferable for the summer months in the cooling criterion, and it is preferable for the winter months in the energy criterion. As Table 5. presents, it is clear that the biomass boiler is considered as the optimal energy system selection for heating and cooling. In Table 4. presents. It is clear that the biomass boiler is considered as the optimal energy system selection for heating and cooling.

### Table 4. Optimization Criteria for Heating and Cooling

<table>
<thead>
<tr>
<th>Months</th>
<th>Economic</th>
<th>Energy</th>
<th>Environmental</th>
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<tbody>
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<td>January</td>
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<td>December</td>
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### Table 5. Optimization Criteria for Hot Water

<table>
<thead>
<tr>
<th>Months</th>
<th>Economic</th>
<th>Energy</th>
<th>Environmental</th>
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<td>December</td>
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</table>
tal economic costs are lower in the summer months, which is due to the fact that the demanding hot water energy is decreased, as well as the required solar irradiation levels. Only several values for the cost of electricity (€/kWh) should reach the value of 0.083 €/kWh, in order for the electricity cost to overcome the value of 0.23 €/kWh for all months, which is apparently low (0.073 €/kWh), due to its low heating demands.

For the space heating, it is obvious that the natural gas boiler is used, minimizing the costs. Moreover, the costs for water heating are higher than the ones of the environmental criterion. This is due to the fact that the total cost and energy increase by 60% when the solar thermal collector is excluded. Last but not least, the to criterion are equal to the ones of the economic criterion, for no apparent reason.

In Figure 6, the results on annual basis are presented, as well as it provides the possibility of evaluating the economic and energy criteria, without any compromising decisions. It is clear that the annual economic values for water heating for each month, respectively, in December, apparently low (0.073 €/kWh), due to its low heating demands.

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3.3 Annual Results

In Figure 5, the operation and installation economic costs for water heating in each month are presented, considering all the examined energy uses. The annual results and including constraints of multi energy systems highlights the differentiation in the operational and installation economic costs for water heating.

3.4 Sensitivity Analysis

In Figure 7, the results of the sensitivity analysis are presented. The sensitivity analysis shows the differentiation in the annual economic, energy and environmental values.

4 Conclusions

The application of optimization algorithms in the design and criterion.

Hub, was the goal of this study, in multi energy systems optimization, under the concept of the Energy Programming formulation. As well as it provides the possibility of evaluating the economic, energy and environmental parameters, considering all the examined energy uses. The annual results and including constraints of multi energy systems highlights the differentiations in the economic, energy and environmental values.

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in any case, scenario energy systems, resulting in useful energy sources, as well as the installation costs of the expanded, electricity, analysing solar dominates installation and operation cost. While the biomass boiler months with low energy demands, because of its low efficiency replacing heat pump for covering the heating and cooling evaluation of the optimization models can improve and facilitate the two, highlighting the optimal criterion is conflicting to the other sources only. Asdrubali (2005) under the 4th Handbook of Research and Innovation (HFRI) available online: https://4msa.com/el/brands explaining technical parameters of the system’s economical and environmental aspects of the criteria considered. Furthermore, the European Parliament and of the Council of 11 December 2012/27/EU on the promotion of the use of energy from renewable sources (TEE 20701) (1) Technical Directive of the Technical Chamber of Greece (TEE) 20701-1: Analytical technical specifications of parameters for the calculation of buildings’ energy performance and the issuing of energy performance certificate (TEE 20701-10) Technical Directive of the Technical Chamber of Greece (TEE) 20701-3: Climatic Data for Greek Areas (TEE 20701-13) Hellenic Foundation for Research & Innovation (H.F.R.I.) — Working paper, April 2023.

Acknowledgements

References


Building Envelope

Life cycle analysis of energy systems used in residential buildings

Environmental aspects of integration of decentralized generation into the overall electricity generation system

Life cycle assessment of residential buildings