Energy Design and Multicriteria Decision Analysis in a New Residential Building - Study on the Application of Thermal Insulation

- In this study, an attempt was made to design and study a new two-storey house with energy planning criteria
- The principles and systems used for building energy planning and the importance of multicriteria analysis in decision-making were analyzed
- The main criterion for the energy efficiency of the construction outside the bioclimatic design was the thermal insulation of the building where multi-criteria analysis was applied with the Visual PROMETHEE application to select the most suitable **thermal insulation material**
- Equal weights of criteria were analyzed, but also different weights calculated through personal interviews with civil engineers
- The results of the two analyses were compared

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- The more complex an issue, the more necessary the standardization of the decision-making process
- Multi-Criteria Decision Making methods give a new perspective where quantitative and qualitative considerations can be taken into account in formulating a decision issue.
- Meeting all the objectives of the decision is not possible because not all alternatives have the same performance across all criteria.
- Alternatives are screened and the ones with the highest performance are selected

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- In terms of the environment, energy needs are constantly increasing, so it is useful to save energy
- A large number of studies have been carried out on energy consumption in buildings and at the same time regulations have defined specific energy saving objectives
- A number of publications have addressed relevant issues

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- The current study examined three diferent insulation materials for a residential house in Greece
- The paper is highlighting the application of PROMETHEE methodology in thermal insulation selection
- Analyses findings and a detailed discussion on the results is provided
- Finally, conlcusions, limitations of research, ideas for further research and proposals for improvement are presented

Methodological Approach

- The purpose of multicriteria analysis is to select the appropriate thermal insulation material according to various parameters that characterize it for the vertical elements of a new residential building
- The thermal insulation materials available on the market today are varied, but after a bibliographical investigation the following three (alternatives) have been selected and used for comparison:
  - ✓ Expanded Polystyrene EPS
  - ✓ Stonewool/ Rockwool
  - ✓ Expanded Cork ICB
- The problem was formulated with evenly distributed criteria weights and unequal criteria weights
- Comparisons were made between the two approaches
- The considered criteria included both quantitative and qualitative criteria.

Table 1 - Criteria and Units of Measurement

CRITERIA	MEASUREMENT UNITS
QUANTITATIVE	
Thermal conductivity coefficient λ	W/m·K
Lifetime	years
Special heat capacity cp	J/kg·K
Cost C.	€/m2
Temperature range	°C
Primary energy content contained	kWh/m3
Vapor diffusion resistance coefficient m	-
QUALITATIVE	**CATEGORIZATION**
Fire resistance	Very Low / Low / Moderate / High / Very High
Resistance to solar radiation	Yes No
Soundproofing	Very Low / Low / Moderate / High / Very High

Table 2 Actions, Criteria And Performance Of Actions Against Each Criterion

Thermal insulation materials	CRITERIA									
	Thermal conductivity coefficient λ (W/m·K)	Special heat capacity c_p (J/kg·K)	Vapor diffusion resistance coefficient m	Lifetime (years)	Cost C (€/m²)	Temperature range (°C)	Primary energy content contained (kWh/m³)	Resistance to solar radiation	Soundproofing	Fire resistance
Expanded Polystyrene EPS	0.031-0.041	1450-1550	20-100	50	2.04-12.5	-50 to 75	250	NO	GOOD	B
Stonewool/ Rockwool	0.033-0.041	840	1- 1.5	30	2.25-13.7	-100 to 750	650	YES	VERY GOOD	A1
Expanded Cork ICB	0.042-0.065	1500-1560	10-40	50	12-25	-200 to 130	15	YES	EXCELLENT	D

Analysis Findings and Discussion

- Initially the implementation of the analysis for different weights highlighted that the **expanded polystyrene** is exceptional, followed by the **stone / rock wool**, while the last position is occupied by the **Expanded Cork**
- In the case that similar criteria weights are considered, the **rock wool** is the last one, and **Expanded Cork** is slightly ahead of the **expanded polystyrene** based on the outcomes of PROMETHEE Rankings
- In the case of different weights, the **cost and thermal conductivity factor** play an important role since they increase the positive flow of expanded polystyrene and at the same time increase the negative flow of the expanded cork

Analysis Findings and Discussion

- Rock wool and expanded polystyrene have the same behavior in response to the temperature range
- Fire resistance helps to increase the net flow of rock wool and at the same time reduces the net flow of expanded cork
- The specific heat capacity and the primary energy content of the two latter materials influence the outcome in an opposite manner
- Materials' life expectancy seems to negatively affect the alternative choice of rockwool
- The other criteria do not play a particularly important role in qualifying some of the alternatives according to PROMETHEE Rainbow

Analysis Findings and Discussion

- In the case of similar weights, all criteria give a negative and positive direction to the alternatives at similarly significant rates
- However, material life expectancy has little effect on the yield of expanded cork and expanded polystyrene, and the resistance to sunlight has little effect on the yield of expanded cork and rock wool
- The criteria of primary energy / sound insulation / fire resistance have little effect on the performance of the expanded polystyrene
- Performance of the expanded cork scores negatively against the specific criteria heat capacity, the primary energy content and the fire resistance
- The net flow of rock wool seems to have no impact on sound insulation and cost according to PROMETHEE Rainbow

Analysis Findings and Discussion

- Comparing the two PROMETHEE Rainbow charts for equal and unequal weights the order of preference changes
- It is reasonable to assume that all criteria play a major role on the net flows of alternatives in the case of unequal weights
- In the case of equal weights, it appears that half the net flows of the same thermal insulation materials are affected
- While in the first analysis (unequal weights) the water vapor diffusion coefficient and solar radiation resistance in the second analysis (similar weights) do not play a significant role in the net flow of expanded polystyrene, the first criterion significantly increases the positive flow while the second criterion increases similarly the negative flow according to PROMETHEE Rainbow.

Conclusions and Future Research

Visual Promethee program had:

- A very user - friendly and simple graphical interface
- Made the presentation of a multi-solution issue easy
- User can make comparisons between different scenarios
- Other scenarios could be created to reduce the demand for energy in buildings and compare with each other to select the best one
- The optimal solution may at any time be different if other evaluation criteria are taken into consideration, especially when the criteria are conflicting

Conclusions and Future Research

- The approach to an issue has a strong element of subjectivity
- The limitations identified in the study are the weights assigned to the criteria
- Accurate weight assignment is not easy because it involves the personal opinion of the participants
- Other population groups, such as home users, could also participate in the research
- The three thermal insulation materials compared had specific performance against each criterion
- One of the objectives of research may be to improve the parameters of each material so that its application would be considered a good solution.

Conclusions and Future Research

- For analysis with different criteria weights, the expanded polystyrene is followed by the stone wool and in the last place resides expanded cork
- In the analysis with the equal criteria weights the best alternative is the expanded cork and the worst is the rock wool
- In the case of different criteria weights the cost, thermal conductivity, temperature range and fire resistance are the criteria that occupy the highest percentages for evaluating alternatives.
- Specific heat capacity, the primary energy content, and the life span affect the performance of some thermal insulation materials to a lesser extent.
- Influence of the other criteria is negligible
- In the case of analysis with equal criteria weights, almost all the criteria equally affect the performance of the thermal insulation materials, either negatively or positively.
- Life expectancy has little effect on the performance of expanded cork and expanded polystyrene.

Conclusions and Future Research

- The resistance to sunlight has little effect on the yield of expanded cork and rock wool
- Primary energy content, sound insulation and fire resistance have little effect on the net flow of expanded polystyrene
- The performance of the cork has little influence on the specific heat capacity, the primary energy content and the fire resistance
- The performance of rock wool does not appear to be affected by the sound insulation and cost of the material
- The shorter stability interval for both cases is found in the resistance to solar radiation

Conclusions and Future Research

- In Greece, there is a large volume of buildings that show high energy consumption without providing users with the necessary thermal comfort conditions
- In recent years, renovation of the existing building stock has been promoted with the appropriate legislative and financial incentives to bring the country in line with European directives requiring a reduction in energy consumption
- Despite today's difficult economic environment, reducing the energy needs of the buildings is a key pillar of growth.
- New buildings should be studied and constructed with the basic principles of energy planning and sustainability
- An effort is made to find solutions that are environmentally friendly and user-friendly
- The complexity of the issue requires a systematic presentation of the objectives and strategies needed to achieve the sustainability of the construction

Conclusions and Future Research

- Reducing energy consumption and protecting the environment is not a hindrance to comfort, cost and aesthetics
- There are a number of simple interventions available in buildings to optimize construction
- Such an investment usually has a depreciation in the short term and then generates a profit if the amount of energy wasted decreases
- More complex operations can then be performed, but expert advice and careful techno-economic study is needed
- The general public has incomplete information regarding energy management

Conclusions and Future Research

- Relevant events organized in municipalities are needed to identify the benefits of building energy planning locally
- Information should refer to the existing institutional / financial incentives for the implementation of energy technologies
- Implement energy planning applications in public buildings
- Promotion is important for legislation to be fully implemented
- Public buildings should develop a system of grading their energy requirements based on Multi-criteria analysis
- Achieving sustainability in buildings is based on the awareness of both experts and users that each building is a living organism that interacts with the environment and is directly linked to quality of life and health

Conclusions and Future Research

- Considering additional criteria for comparing alternative actions taking into account: installation costs
- Addition of other thermal insulation materials as alternatives
- Multi-criteria analysis with another method for comparing results