Regular Paper

(6) 1

Energy Management in Buildings: A Systems Approach

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Received 8 January 2007; Accepted 10 January 2008, after one or more revisions
Published online 8 May 2008 in Wiley InterScience (www.interscience.wiley.com)
DOI 10.1002/sys.20099

ABSTRACT

Systems approach is used to enhance the energy performance of an existing building by holistically examining it as a "sociotechnical" system. A student dormitory in the city of Xanthi, Greece, is used as a case study to identify the most appropriate interventions according to the principles of sustainability. In this context, a framework is developed that could be extensively used for energy management of existing buildings as well as of new ones. The "system methodology" of this framework breaks through the limited scope of engineering analysis and emerges as the only available tool to implement the principles of sustainability. © 2008 Wiley Periodicals, Inc. Syst Eng 11: 263–275, 2008

Key words: energy management in buildings; systems approach; sustainability; sociotechnical systems

1. INTRODUCTION

It is argued here that the systems approach is a powerful "strategy" for energy management in existing buildings because it has been applied successfully in a variety of major problems. Its main advantage is that it examines holistically the reference system (a building in this case) and the environment in which it operates. It considers all the factors that may affect its energy efficiency and evaluates the possible interventions and their results not only from an economic, technical, and energy viewpoint, but also from an environmental, social, and financial perspective. This approach is in tune with the definition of sustainability proposed by Pearce, Barbier, and Markyanda [1990], according to which sustainability is viewed as a vector of various desirable social objectives. The elements to be included in the vector are open to ethical debate.

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Systems Engineering, Vol. 11, No. 3, 2008

The existing problems of scarce energy resources and sustainable energy management, which are connected to other problems such as pollution and deteriorating living conditions in residential buildings, can be effectively tackled with solutions that result from the application of systems thinking. To the authors' knowledge, several references exist in literature for technical interventions to improve the energy efficiency of a building, but the efforts that have been made to analyze the energy system of a building as a "sociotechnical system" and to propose changes in consumption behaviors focused on energy saving are limited. For the purpose of this work, systems engineering, in its most comprehensive form, is applied to a building used as a student dormitory in the city of Xanthi, Greece.

Within this framework, the lack of energy efficiency is determined and quantified as a problem, and the reference system, as also its hypersystem, parallel systems, and subsystems and their interactions are defined. Historical data of the reference system are collected and the existing energy consumption is analyzed. Next, both organizational and technical interventions are determined and evaluated, using multicriteria analysis based on economical, financial, technical, environmental, social, and energy saving aspects, to identify what contributes to achieving a sustainable solution to the problem. An Intervention Plan is formed considering different sets of criteria weights (with technical, social and environmental bias). The plan, if implemented, will substantially improve the energy efficiency of the building under study.

2. BACKGROUND ON ENERGY MANAGEMENT IN BUILDING SECTOR

Energy-related CO_2 emissions continued to rise globally to 11.8 billion tonnes in 2000, an increase of 14% over those of 1990. Improvements in overall energy efficiency, although sometimes accompanied by a reduction in carbon intensity (as the measure of carbon emissions versus primary energy), have not been enough to offset the overall increases in energy demand and in CO_2 emissions [IEA, 2002]. In 1990, the building sector (residential, commercial, and institutional) was responsible for roughly one-third of the global energy consumed and for associated carbon emissions [Watson, Zinyowera, and Moss, 2006]. In 2000, energy consumption in the residential/commercial sector in Organization for Economic Co-operation and Development (OECD) countries was 1.189 Mtoe (million tonnes of oil equivalent), an increase of 15% over that of 1990. The current challenge is to seek *sustainable* development, while maintaining high energy consumption as required by the living and comfort standards in developed countries. Achieving energy savings has become a high priority in the political agenda of most countries. Following the Energy Policies of International Energy Agency (IEA) Countries Review 2002 [IEA, 2002], under the IEA's *Shared Goals* adopted in 1993, IEA Member countries sought to create conditions in which the energy sector of their economies can make the fullest possible contribution to sustainable economic development and the well-being of their population and of the environment.

Accordingly, the building energy legislation at EU level was spelled out in Council Directive 93/76/EEC [EEC, 1993], Directive 2002/91/EC [EU, 2002] and the Green Paper [Commission of the European Communities, 2001]. This legislation highlights the priority accorded by the EU for reducing energy consumption in the building sector, both for reaching the targets of international agreements (Kyoto protocol and forthcoming commitments) as well as for reducing energy dependency, and hence for attaining sustainable development [Rey, Velasco, and Varela, 2007].

The complex subject of energy management in buildings has attracted the attention of many researchers, and many methodologies and tools have been developed to tackle the problem. Among them, Santamouris et al. [1996] and Önüt and Soner [2006] presented measures to reduce energy consumption in buildings, like hotels. Vicente [1998], alluding to the intangible connection between people's actions and the resulting consequences in energy consumption in the residential sector, stressed the need to measure how the occupants influence energy consumption. Chow et al. [2006] proposed the measures that must be taken up at the early project stage (construction) of the buildings and focused their attention on special measures, like centralized solar water-heating systems. Chung et al. [2006] developed a benchmarking model which could be used in policy analyses, but its highly technical nature may discourage the end-users from using it.

Many scientific papers have focused on the energy-efficiency indicators and their importance. Simple indicators, like the Energy Use Intensity (EUI), which expresses the energy consumption per floor area [Filippin, 2000; Birtles and Grigg, 1997], as well as more complicated ones, like the predicted EUI based on the Sharp's [1996] method, were used in the process of developing the Energy Star benchmark.

Additionally, according to data presented by Watson, Zinyowera, and Moss [2006], residential buildings are expected to account for a substantial part of the total energy consumption in buildings (about 60% of the energy to be used by global buildings in 2010, falling to 55% by 2050). Based on these estimates, specific scenarios indicate that residential buildings will use energy that produces 1.5 Gt of carbon emissions in 2010, 1.6 Gt in 2020, and 2.1 Gt in 2050. Efficiency measures with paybacks to the consumer of 5 years or less have the potential to reduce carbon emissions of global residential and commercial buildings in the order of 20% by 2010, 25% by 2020, and up to 40% by 2050. Most of these reductions will be feasible only in new commercial buildings, as retrofits to the walls and windows of existing buildings are costly. According to Olofsson, Meier, and Lamberts [2004], ASHRAE Standard 90.1 [2001] is a well-used standard for measuring the energy efficiency of buildings in the design stage. Energy rating of an occupied building is more complicated, because the influence of at least the occupants has to be factored in one way or another. Simulation approaches alone cannot even peripherally address important aspects of construction, operation and maintenance. Therefore, energy saving management for existing buildings must adopt proper strategies, over and above those used for new buildings.

3. SUSTAINABILITY THROUGH THE SYSTEMS APPROACH

Sustainability is based on the principle that society should use the available resources on a scale consistent with "the ability of future generations to meet their own needs" as stated in the famous Brundtland report [1987]. The achievement of sustainable development necessitates a coordinated effort in all areas of society to meet the appropriate criteria. Among others, energy saving as well as environmental pollution and global climate change are of paramount importance in today's world and sustainable energy management should cover at least technical, social, and environmental aspects.

Moreover, to foster changes in consumption patterns, interventions are needed not only on the technological front (i.e., production processes, electrical equipment, and appliances), but also on the behavioral front (i.e., equipment operation behaviors and quality of life requirements). That is, managing the demand side of energy market requires inducing changes in consumer lifestyles and consumption behaviors, which are innately onerous for intervention [Cheng, 2005].

It is increasingly accepted that the gap between technical progress, and the understanding of socio-economic aspects and market behavior, is one of the reasons for insufficient implementation of the best available solutions to achieve sustainability in different sectors, including the energy sector [2nd European Symposium, 2004]. To fill this gap, systems thinking could be used to link aspects like energy-efficiency, environmental protection, cost reduction and social acceptance. According to Daly's [1993] second principle, technological innovation is an important factor in reducing humanity's ecological impact, but social, institutional, and organizational innovations are equally important. Indeed, a more balanced (systems) approach that integrates and cooptimizes innovation in all fronts is likely to be more effective in satisfying the basic needs while augmenting the resources.

A "system" is defined as a set of interacting elements exhibiting an overall behavior beyond the behaviors of its individual parts [Calvano and John, 2004]. An "engineering system" is defined as a system designed by humans having some purpose [Magee and de Weck, 2002]. The point of systems theory is to describe entities as systems, especially on a transdisciplinary level that is applicable to any discipline of science and belonging to none of them exclusively [Mulej et al., 2004]. According to Sage and Lynch [1998], systems engineering may be viewed as a process-based effort that comprises a number of activities that:

- assist in the definition of a system that will be trustworthy, of high quality, and cost-effective in meeting user needs
- transform the resulting set of requirements and specifications into a system through various development efforts
- provide for deployment of the system in an operational environment.

The energy performance of a building, viewed as a complete system, is determined by the building's response to the outdoor environment and the indoor conditions. Performance depends on many exogenous variables and can be improved by applying measures (interventions). Given the very large number of possible interventions that may be combined to reach the goal of sustainable energy management in a particular building, determining the most efficient plan of interventions becomes a complex problem. Thus, the focus of this work is to use (1) systems thinking to develop a simple model and to recognize the possible interventions in every system component, including technical as well as managerial interventions, and (2) relative analysis tools, like multicriteria analysis, to evaluate the interventions against sustainability criteria, that is, economic, environmental, and social concerns.

The proposed Intervention Plan includes the approved interventions ranked according to the sustainability criteria. By implementing this plan it is likely to meet the intended targets and achieve sustainable energy management of the system.

The systems approach, which is outlined in Figure 1 as applied to technical projects, is employed to improve the energy situation of a building. According to this methodology, the **problem definition** phase deals with identification of the system under consideration (hereafter referred to as the *reference system*), its components (subsystems), and the interactions among them. The reference system and its parallel systems operate in a hierarchically broader environment which is referred to as the hypersystem. All these systems constitute possible areas for taking actions to tackle the problem. Quantitative *objectives* that contribute to the satisfaction of a *need* are defined and then both *exclusion* and *evaluation* criteria are developed to assess alternative solutions. The elements and factors taken into consideration specify the *scope* of the analysis.

In the **problem analysis** phase, alternative solutions (possible *interventions*) are detailed in both technical and managerial terms. Interventions that are technologically nonfeasible or nonconforming to the *exclusion* criteria are eliminated from further consideration and the remaining ones (acceptable solutions) are assessed according to the *evaluation* criteria. The resulting "optimal" solution is implemented in the **problem synthesis** phase and the results of the actions taken are evaluated to examine if the need is satisfied. According to this description of systems approach, in the present work, the system is, as Rapoport [1953] says, "a part of the world, which is sufficiently well-defined to be the object of an inquiry".

4. THE CASE STUDY

The proposed method is applied to a two-story building, which is used as a student dormitory in the EKTENEPOL area in the city of Xanthi, Greece. Technical information and design documentation of the building, and real data on the total electricity and thermal energy consumptions for the operation of the building during the three years 2002–2004, were gathered during several site visits and audits. All available energy consumption data were analyzed, and the current energy situation is presented in Figure 2. Losses to environment are calculated as the difference between total thermal energy input and estimated thermal energy used. Based on these results, the Mean Annual ELectric Energy Consumption (MAELEC), the Mean Annual THermal Energy Consumption (MATHEC), and the Mean Annual TOtal Energy Consumption (MATOEC), considering the total surface, are 24.9 kWh/m^2/yr, 164.4

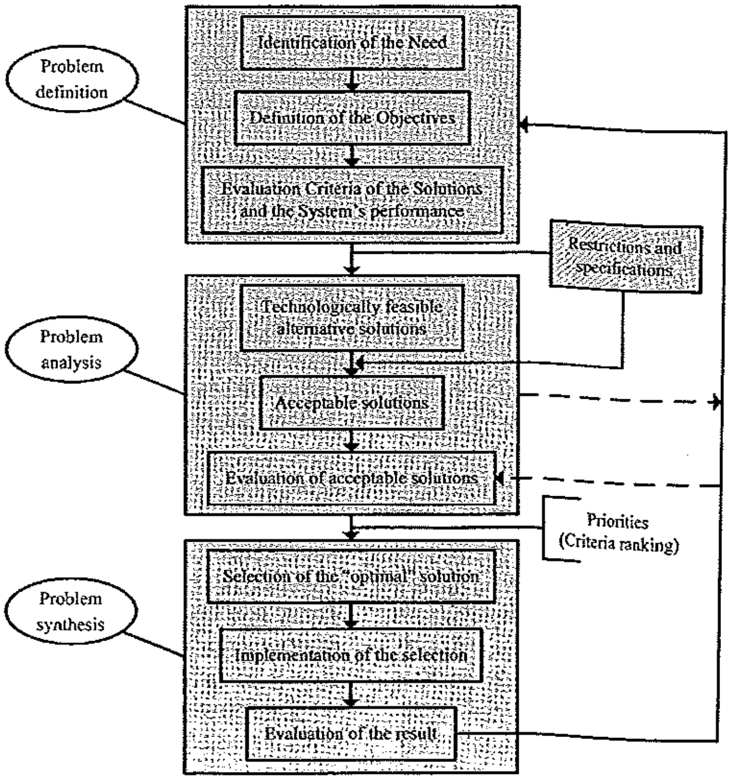

Figure 1. Systems approach in technical projects [Panayiotakopoulos, 2004].

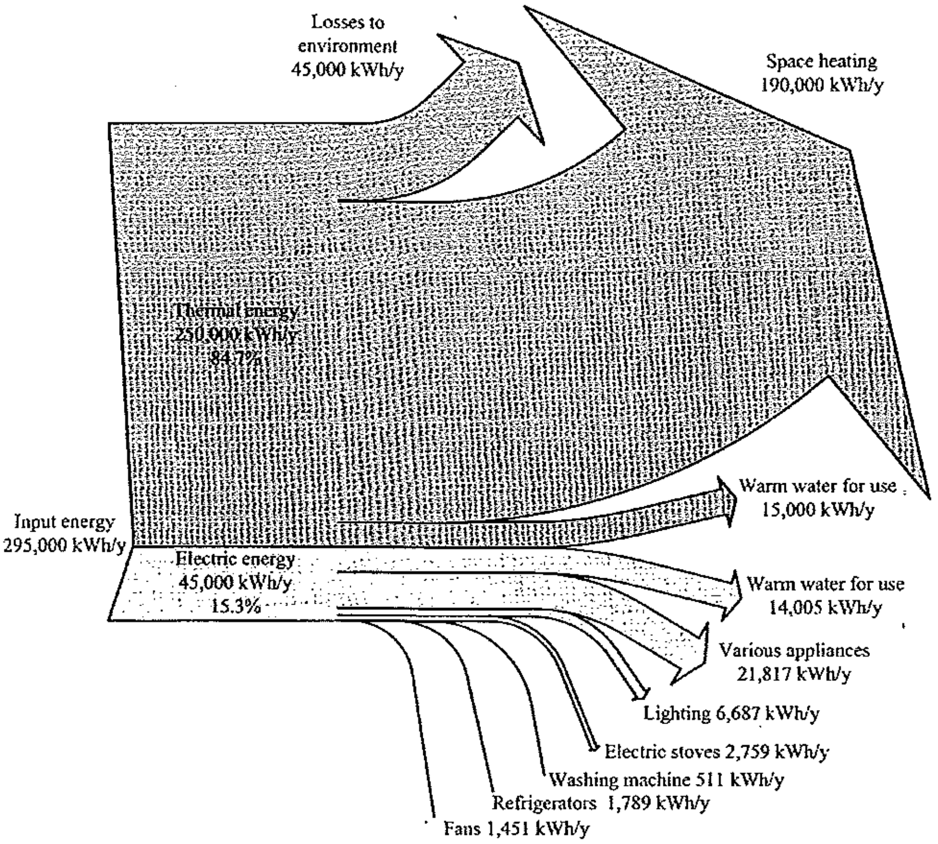

Figure 2. Annual energy consumption in the building (existing situation).

kWh/m²/yr, and 189.3 kWh/m²/yr, respectively, and, considering the covered surface, the corresponding figures are 36.1 kWh/m²/yr, 238.4 kWh/m²/yr, and 274.5 kWh/m²/yr.

4.1. Problem Definition

Identification of the Need. According to an unofficial classification [Trend, 2001], the MATOEC of old buildings is expected to range roughly between 56.1–125 kWh/m²/yr (referred to total surface). The MATOEC for buildings under forthcoming legislation is expected to be less than 56 kWh/m²/yr and that for specially designed buildings to be less than 28 kWh/m²/yr. This preliminary technical evaluation revealed that the energy consumption is currently too high (189.3 kWh/m²/yr) as compared to the benchmarks and hence the need to improve the energy efficiency of the building.

Definition of Objectives. The emerging problem is how the energy balance of the building can be improved in such a way that living conditions in the building are comfortable and at the same time (a) the University Housing Service (university budget) is charged with lower operation cost and (b) the environmental impact is minimal. Considering the energy behavior of the building, a feasible quantitative objective was set: to reduce the total energy consumption by 35% with proportional reduction of air pollutant emissions. If this goal is achieved, the MATOEC will be within the range expected for existing buildings.

Exclusion and Evaluation Criteria. A typical elementary multi-criteria analysis is employed to evaluate the proposals for improving the building's energy consumption. The exclusion criteria with their limiting values and the evaluation criteria with their corresponding sets of weight coefficients, shown in Tables I and II respectively, represent three different aspects of the energy saving problem. Thus, they reflect the viewpoints of the following social groups:

- the Technical Services personnel of the University for technical bias criteria
- the residents of the building for social bias criteria
- the Environmental Department personnel of the community for environmental bias criteria.

Table I. Exclusion Criteria and Limiting Values

Exclusion criterion	Limiting values
1. Initial investment	<100000 €
2. Net present value	> 0
3. Internal rate of return	>6%
4. Benefit-cost ratio	> 1
5. Payback period	<10 years
6. Compliance with legislation	required
7. Technical report	required
8. Sustainability	required
9. Technical support	required

None of the research team members was a stakeholder, directly or indirectly, with the data and results involved in the case study, and hence the reported results are unaffected by research bias. This is important to ensure the Internal, External, and Construct Validity as well as the reliability of the case study [Friedman and Sage, 2004]. Oral interviews were carried out with a different social group each time. Based on the collected data, the proposed weighting factors were presented to the three social groups for approval. After the necessary negotiations, the final weighting factors were accepted by each social group. The goal of this weight setting exercise was to test the sensitivity of the final intervention proposal to a variety of reasonable social attitudes. No claim is made of making a rigorous statistical analysis of opinions, which would be of no practical significance as will be explained in the concluding section. Furthermore, a score scale of 5–10 is used for each evaluation criterion, while the exclusion limiting values and the scaled scores used are empirical. An intervention receives no grade if it has zero contribution to the corresponding criterion.

4.2. Problem Analysis

The reference system is the energy system of the building composed of the electric and thermal energy consumption network (Fig. 3). According to Karlsson [2006], it is essential to find the components of the system, how they are connected, the boundary and the connection between the system and its surroundings. In this case, the hypersystem to which the reference system belongs is the total building that consists of the water supply and drainage networks, the structural elements of the building (building shell) and the residents of the building (*parallel systems*). The subsystems contained in the reference system are:

- the "Thermal energy producers" composed of the burner and the boiler
- the "Thermal energy consumers" composed of radiators and hot water for domestic use
- the "Hot water distribution networks" composed of piping, circulators and thermostats
- the "Electricity consumers" composed of the typical electric appliances in each apartment such as white goods (e.g., electric stoves and refrigerators), TV sets, PCs, lighting devices, and fans. Moreover, the boiler (when used for heating water for domestic use during summer months), the burner and the circulators fall into this subsystem as well, because they are powered by electricity.
- the "Electricity distribution network" composed of cables and devices required to transfer electricity from Public Power Corporation (PPC) network to the subsystem "Electricity consumers."

Table II. Evaluation Criteria and Weights

Evaluation criterion	Weight 1*	Weight 2*	Weight 3*
A_1 Initial investment	0.15	0.10	0.10
A_2 Payback period	0.10	0.10	0.05
B. Financing of investment	0.05	0.05	0.05
C_1 Electricity saving	0.15	0.15	0.15
C_2 Thermal energy saving	0.15	0.10	0.15
D. Reduction of CO_2 emissions	0.15	0.15	0.25
E_1 Safety and functionality	0.05	0.05	0.05
E_2 Ergonomic installation	0.05	0.05	0.05
E_3 Technical report	0.05	0.05	0.05
F_1 Extent of changes	0.05	0.10	0.05
F_2 Duration of interventions	0.05	0.10	0.05

weight 1*: according to technical bias criteria.
weight 2*: according to social bias criteria.
weight 3*: according to environmental bias criteria.

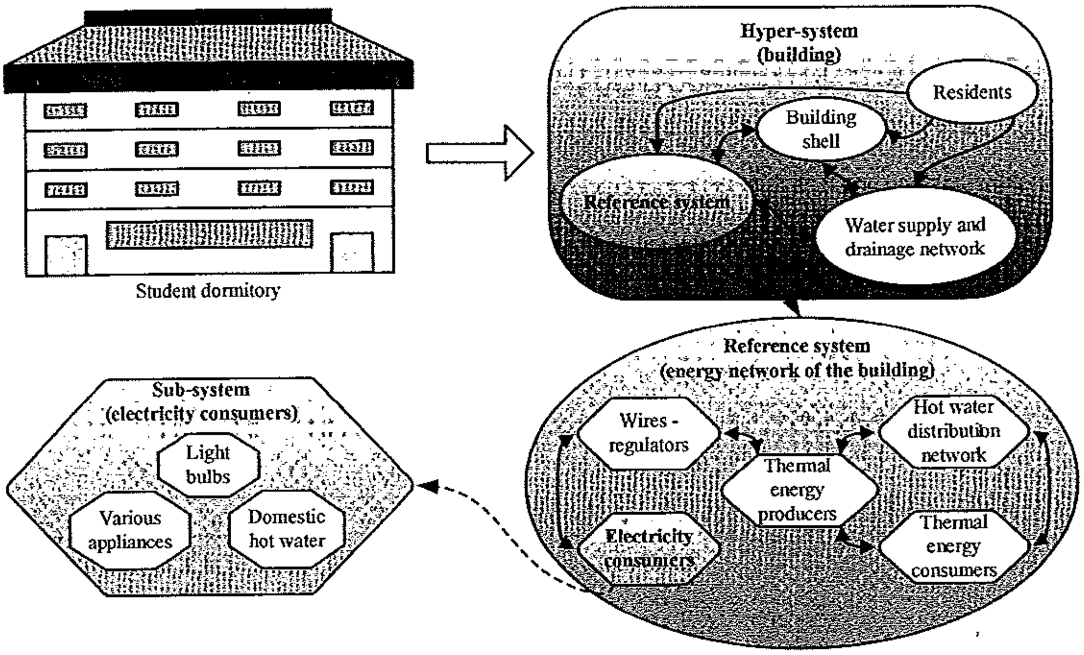

Figure 3. Graphical representation of the reference system.

Electricity and fuel oil are considered the input to the reference system, and quality of living conditions (at certain cost of electricity and fuel oil) the output. All the electricity supplied and the thermal energy produced are consumed in the system, but during the process of converting these inputs to the desired output there is emission of pollutants as well as thermal pollution. The whole system operates at a steady state and is connected to the public energy network. When certain events happen, e.g., failure of a producer (boiler), a higher input of electricity from the power supplier (Public Power Corporation—PPC) is possible to satisfy the thermal energy needs. However, the system cannot operate autonomously. Any abrupt power outage from the PPC causes failure of the system, namely, stoppage of almost all activities. The system would then operate with a partial feedback, in the sense that it responds to some changes in ambient conditions, like users' specific needs for warm water, but not to all of them (e.g., the system does not monitor its consumption in relation to weather data and does not correspond to peaks in consumption).

4.2.1. Alternative Solutions

Several technical and organizational interventions distributed to the subsystems, parallel systems, and hypersystem are determined based on experience and literature data and are examined thereafter. Table III includes all the recognized interventions per system (sub, parallel, and hyper). Analytical description and data of all interventions, as well as calculations pertaining to energy saving, environmental, and economical results can be found in Kouloura, Genikomsakis, and Protopapas [2006] and Kouloura, Genikomsakis, and Hatzi [2004]. Details in respect of the investment cost of each intervention, the expected energy saving (electric and thermal), the economic profit, and the reduction in emission of CO_2 are given in Table IV. If all these interventions are applied, the energy consumption, the environmental impact, and the energy situation of the building will improve [CRES, 2000]. Taking into account the exclusion and evaluation criteria, it has to be determined which of these interventions is the most appropriate one to solve the problem.

Based on the data presented in Table IV, all the recognized interventions are checked against the exclusion criteria and three of them are excluded from further consideration, because they do not fulfil all the exclusion criteria. Specifically the intervention "Photovoltaic system installation" has a payback period of more than 10 years (which is the limit value). The intervention "Conventional fuel replacement" cannot be realized, because currently there is no access in the natural gas network from the Xanthi area. The intervention "Roof insulation" has a negative net present value.

4.2.2. Evaluation of Solutions

The technologically feasible interventions as well as those conforming to the *exclusion criteria* are graded on each *evaluation criterion*. The weighted grades of

Table III. Identified Interventions per System

Item	Description
A. Interventions in the sub-systems of the reference system	
A.1.	Measurements schedule
A.2.	Replacement of the light bulbs
A.3.	Solar heater installation
A.4.	Photovoltaic system installation
A.5.	Adjustment of burner-boiler system
A.6.	Replacement of burner
A.7.	Replacement of piping
A.8.	Zoned heating system
A.9.	Zoned heating system with weather compensator
A.10.	Conventional fuel replacement
B. Interventions in parallel systems	
B.1.	Roof insulation
B.2.	Windows draught-proofing
B.3.	Limit of energy consumption
C. Interventions in the hyper-system	
C.1.	External environment shaping
C.2.	Night ventilation

the interventions are calculated for the three different sets of weight coefficients and presented in Table V.

Some mutually exclusive interventions are identified, e.g., conversion to a "zoned heating system" required "replacement of piping" and installation of a different type of piping network. In evaluating the interventions, certain factors were considered constant, an assumption that could be proven unrealistic in future.

Table IV. Energy, Economic, and Environmental Repercussions of Interventions

Interventions	Energy saving		Cost (€)		Profit (€/y)	CO_2 reduction (kg/y)
	Electric (kWh/y)	Thermal (lt fuel oil/y)	Invest-ment	Operation		
Interventions in the sub-systems						
Measurements schedule	1,500	750	1,500	225	524	3,231
Replacement of light bulbs	5,433	0	273	0	462	4,618
Solar heater installation	11,424	0	6,960	70	971	9,710
Photovoltaic system installation	14,668	0	48,000	240	1,247	12,468
Adjustment of burner-boiler system	0	848	600	0	448	2,211
Replacement of burner	931	1,828	750	0	1,044	5,559
Replacement of piping	0	7,206	10,500	0	3,805	18,792
Zoned heating system	0	9,608	17,940	100	5,073	25,056
Zoned heating system with weather compensator	0	12,010	19,940	100	6,341	31,320
Conventional fuel replacement	1,864	0	2830	200	7,278	24,573
Interventions in parallel systems						
Roof insulation	0	2,662	15,185	0	1,406	6,942
Windows draught-proofing	0	552	78	0	291	1,440
Limit of energy consumption	5,000	0	0	0	425	4,250
Interventions in the hyper-system						
External environment shaping	>0	>0	0	300	>0	-
Night ventilation	>0	0	0	0	>0	-

Table V. Grades and Total Weighted Grades of Interventions

Interventions	Evaluation criteria											Total 1	Total 2	Total 3
	A1	A2	B	C1	C2	D	E1	E2	E3	F1	F2			
Replacement of burner	10	10	0	6	7	8	10	10	10	8	8	7.95	7.90	7.75
External environment shaping	10	10	0	6	6	7	10	10	10	10	10	7.85	8.05	7.55
Measurements schedule	9	9	0	7	6	7	10	10	8	8	6	7.35	7.30	7.15
Adjustment of burner-boiler system	10	9	0	0	6	10	10	10	10	10	10	7.30	7.50	7.35
Replacement of light bulbs	10	10	0	8	0	7	10	10	10	10	10	7.25	7.75	6.95
Limit of energy consumption	10	10	0	8	0	6	10	10	10	10	10	7.10	7.60	6.70
Night ventilation	10	10	0	0	6	7	10	10	10	10	10	6.95	7.15	6.65
Windows draught-proofing	10	10	0	0	6	6	10	10	10	10	10	6.80	7.00	6.40
Zoned heating system with weather compensator	6	8	0	0	10	10	10	9	10	6	6	6.75	6.55	7.05
Zoned heating system *	6	8	0	9	0	10	10	9	10	6	6	6.60	6.90	6.90
Solar heater installation	7	7	0	9	0	8	9	9	10	8	7	6.45	6.85	6.55
Replacement of piping *	6	9	0	0	8	9	10	9	10	6	6	6.40	6.30	6.55
Photovoltaic system installation	-	-	-	-	-	-	-	-	-	-	-	0	0	0
Conventional fuel replacement	-	-	-	-	-	-	-	-	-	-	-	0	0	0
Roof insulation	-	-	-	-	-	-	-	-	-	-	-	0	0	0

Total 1: the weighted grade of Intervention according to Technical bias criteria.
Total 2: the weighted grade of Intervention according to Social bias criteria.
Total 3: the weighted grade of Intervention according to Environmental bias criteria.
*: excluded.

Following are some important factors that may influence the environment of the system and subsequently the reference system itself:

- *Cost accounting of electricity:* The unit cost of electricity was considered constant, independent of the consumption and the hour during a day. However, with the prevailing tendencies in the electricity market and forecasts for future, after the completion of liberalization of the energy market, the cost per kWh is expected to increase. It is also expected that residential customers, who currently do not have the option to choose their energy supplier (as in the studied case), will be given the option to pay the daily and hourly electricity unit cost.
- *Improvement of consumption of reactive power:* The PPC currently debits all residential consumers a common tariff that is independent of the consumption of reactive power. It is first proposed to install meters and recorders of cos φ (power coefficient), whose readings can be used to calculate consumption of reactive power [Greek Ministry of Development, 2002]. Then, if these values correspond to a system that operates correctly, negotiation could begin with the supplier (PPC) to decrease the debit of reactive power. Otherwise, how to increase cos φ should be examined by installing compensating capacitors and then proceeding to negotiate debit of reactive power with the supplier.
- *Financing of intervention for energy saving:* Private companies can receive some subsidies for interventions resulting in energy savings through European Programs. The percentage of such subsidies reaches up to 50%. If private investments in the reduction of energy consumption in buildings are included in a new European Program, the proposed interventions become more attractive.
- *Fluctuation of natural gas price:* The price of natural gas in Greece is still controlled by the government and is linked to the price of fuel oil. Aiming at more competitive prices, the Directive 2003/55/EC [EU, 2003] proposes to liberalize shortly (by the end of 2007) the market of natural gas. Although the prices are widely anticipated to fall, future prices of natural gas are likely to become uncertain. Consequently, it is not clear whether the economic evaluation of the interventions made herein is conservative or optimistic.

Table VI. Intervention Plan Based on the Three Sets of Criteria Weights

Intervention	Priority 1	Priority 2	Priority 3
Replacement of burner	1	2	1
External environment shaping	2	1	2
Measurements schedule	3	6	4
Adjustment of burner-boiler system	4	5	3
Replacement of light bulbs	5	3	6
Limit of energy consumption	6	4	7
Night ventilation	7	7	8
Windows draught-proofing	8	8	10
Zoned heating system with weather compensator *	9	-	5
Zoned heating system *	-	9	-
Solar heater installation	10	10	9
Replacement of piping *	-	-	-

*: mutually exclusive.
Priority 1: based on Technical bias criteria.
Priority 2: based on Social bias criteria.
Priority 3: based on Environmental bias criteria.

- *Cost of money:* As the interest rates have been tending to decrease recently, 6% was considered the discount interest rate in the market. In this case, the cost of money over time will decrease and the economic profit from the interventions over the ten years of operation will be higher in terms of present value.

4.3. Problem Synthesis

As Christopher [2007] argues, "...scientists realized that reality cannot be understood completely through classification and analysis. Something more was needed. The 'something more', a synthesis, was discovered and developed over the years by scientists and a new science—system science was born." Following this explanation for the necessity of a problem synthesis phase (Fig. 1), an Intervention Plan is formed based on technical bias criteria. The Plan contains the most appropriate interventions to be implemented, which are prioritized according to their score and presented in Table VI as Priority 1. Implementation of the proposed measures will result in a decrease of the annual energy consumption as shown in Figure 4. When the other two sets of criteria are used, namely, criteria with environmental and social bias, practically the same set of top six interventions are obtained with small variation in ranking (Table VI).

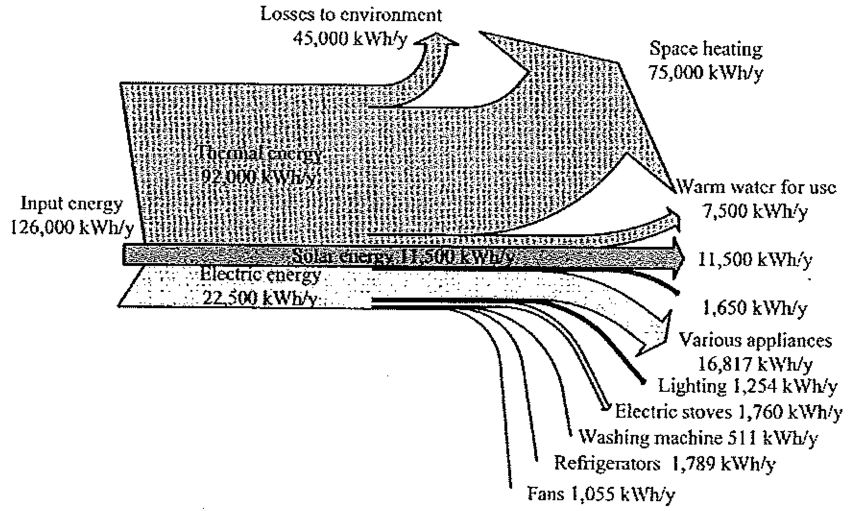

Figure 4. Annual energy consumption in the building (future situation).

Implementation of selected interventions. After the completion of all the proposed Priority 1 interventions in the building, the MAELEC, MATHEC, and MATOEC, as applied to total surface, are expected to be 12.5 kWh/m^2/yr, 60.5 kWh/m^2/yr, and 73 kWh/m^2/yr, respectively, or, correspondingly, 18.1 kWh/m^2/yr, 87.7 kWh/m^2/yr, and 105.8 kWh/m^2/yr, as applied to covered surface. With the proposed interventions, it is calculated that the future consumption of thermal energy will drop by up to 158,000 kWh/y, equivalent to 15,988 lt fuel oil/y (63.2% of existing consumption), and electricity by up to 22,500 kWh/y (50% of existing consumption). Also, the CO_2 emissions will be decreased by 62.2% as compared to the present situation.

Evaluation of the results. Consequently, in future, the energy behavior of the building (73–105.8 kWh/m^2/y, as applied to total and covered surfaces respectively) will be within the limits for old buildings (56.1–125 kWh/m^2/y) according to the unofficial classification. In the future situation, the objectives set (see Section 4.1) will be achieved and MATOEC of the building will be in the range expected for existing buildings.

5. CONCLUSIONS

The present work demonstrates that systems approach could be easily and usefully employed to analyze an existing building as a "sociotechnical" system and to identify its component parts that influence its energy behavior. The main advantages of this form of analysis are that it incorporates the principles of sustainability and that it enables the analyst to determine not only the technical, but also the organizational procedures amenable to interventions for saving energy, in contrast to the commonly used methods that focus mostly on technical aspects only. Moreover, although this approach is applied to an existing building, it is applicable to new buildings as well.

Additionally, to manage the energy consumption using sustainability principles in an appropriate and methodical manner, the feasible interventions are prioritized through multicriteria analysis. Considering three different sets of weights that represent the viewpoints of three engaged social groups, the most suitable interventions are selected based on their priority. For this case study, the Intervention Plan is almost the same for the three sets of criteria weights (technical, social, and environmental bias) with small ranking variations between the interventions. However, if different exclusion criteria (e.g., Investment cost < 20.000 EURO) or different weights for evaluation criteria are used, then the set of proposed interventions are expected to differ significantly.

ACKNOWLEDGMENTS

The authors express their gratitude to the Editor-in-Chief and the four anonymous reviewers whose comments led to significant improvements of this paper.

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