EXERGY ANALYSIS FOR SUSTAINABLE BUILDINGS

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Contents

Summary

Achieving sustainable solutions to today's energy and environmental problems in residential sector, particularly for buildings, requires long-term planning and actions. Energy issues are especially prevalent at present and renewable energy resources appear to provide one component of an effective sustainable solution. An understanding of the thermodynamic aspects of sustainable development can help in taking sustainable actions regarding energy. Discussed in this article are possible future energy-utilization patterns and related environmental impacts, potential solutions to current environmental problems, renewable energy technologies and their relations to sustainable development, and how the principles of thermodynamics via exergy can be beneficially used to evaluate energy systems and technologies as well as environmental impact. Throughout the article potential utilization of exergy analysis to achieve sustainable buildings is considered and applied to three cases considered for applications.

1. Introduction

Society faces many environmental problems, spanning a continuously growing range of pollutants, hazards and ecosystem degradation over ever wider areas. The most significant problems are global climate change, stratospheric ozone depletion and acid precipitation. The former is potentially the most important environmental problem relating to energy utilization. Increasing atmospheric concentrations of greenhouse gases are increasing the manner in which they trap heat radiated from the earth's surface, thereby raising the surface temperature of the earth and increasing sea levels, as a consequence. Many potential solutions are proposed for current energetic, environmental and sustainability problems. These include efficient energy use, cleaner technologies, renewable energy sources, alternative fuels (e.g., hydrogen), etc.

Historical evidence proves that the massive emissions of greenhouse gases expelled from various sectors, ranging from industrial to residential, in the atmosphere in the last century can be corroborated with the global temperature increase, which reflects the global warming phenomenon. This is clearly shown in Figure 1 as the global temperature anomaly since 1860.

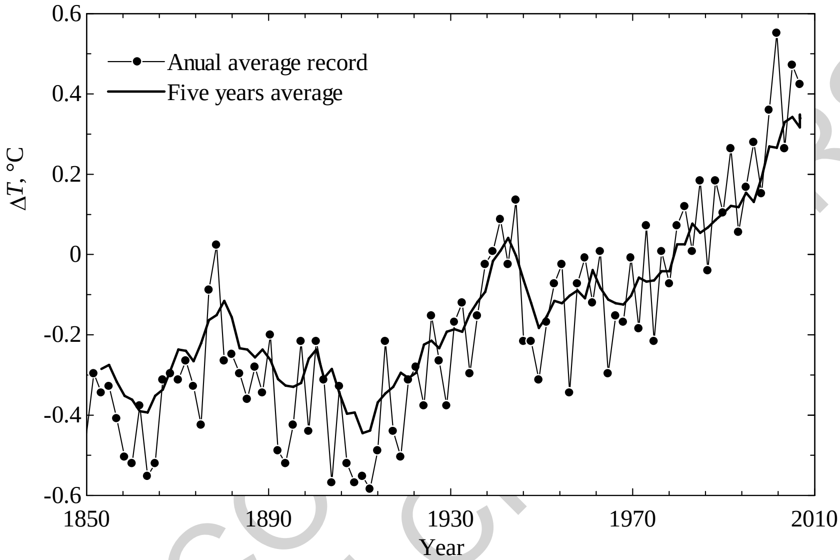

Figure 1. Variation of global temperatures (data from: Brohan P., Kennedy J.J., Haris I., Tett S.F.B., Jones P.D. (2006). Uncertainty estimates in regional and global observed temperature changes: a new dataset from 1850. Journal of Geophysical Research 111: D12106).

Solutions for sustainable residential sector are needed to meet the sectoral needs of individual houses, building complexes, and communities in an environmentally, ecologically, economically and socially acceptable manner without compromising the ability of future generations to meet their own needs. It also requires the use of renewable energy resources and sustainable fuels. The primary goals of sustainable residential sector are to achieve safe, efficient, effective, economic, viable, reliable and environmentally benign community systems. In this regard, six primary pillars as global targets are introduced to help accomplish the above listed goals:

- better efficiency,
- better cost effectiveness,
- better use of energy resources,
- better analysis and design,
- better performance improvement,
- better environment, and
- better sustainability.

These will also result in numerous other benefits, such as: enhanced economic growth and competitiveness; reduced congestion, greenhouse gases, smog, and land and water pollution; and improved health and wealth.

Sustainable development demands a sustainable supply of energy resources that, in the long term, is readily and sustainably available at reasonable cost and can be utilized for all required tasks without causing negative societal impacts. In order to achieve sustainability in residential sector for buildings, it is extremely important to choose right energy sources, analyze and design the energy systems in the right way, and utilize sources and systems in the right way with no environmental consequences. By doing so, we will meet the society's desire to be sustainable. The primary objective of this article is to discuss how exergy analysis, as a potential tool, can help make buildings more sustainable and contribute to local and global sustainable development. This article also demonstrates how exergy methods provide a useful tool for improving efficiency, cost effectiveness, environmental impact and hence sustainability. Further discussions are made on energy use in building and analysis of various aspects under exergy criteria with some case studies and applications to highlight the importance of the topic.

2. Energy and Buildings

During the past two decades the primary energy demand has increased, especially in residential sector, due to increasing population and industrialization worldwide. In most countries, buildings are primarily responsible for at least 40% of total energy consumption. Figure 2 shows the percent energy consumptions in various countries, with a lowest percentage for Finland as 16% to a highest percentage of 50% for Saudi Arabia. It is obvious that the percentage has become much more in fast developing countries, from China to India and Brazil, as residential and commercial sectors have expanded recently and their energy demands have increased drastically for particularly building heating and cooling applications. The key issue is of course not only the type of energy used but also its consequences on the environment and sustainability.

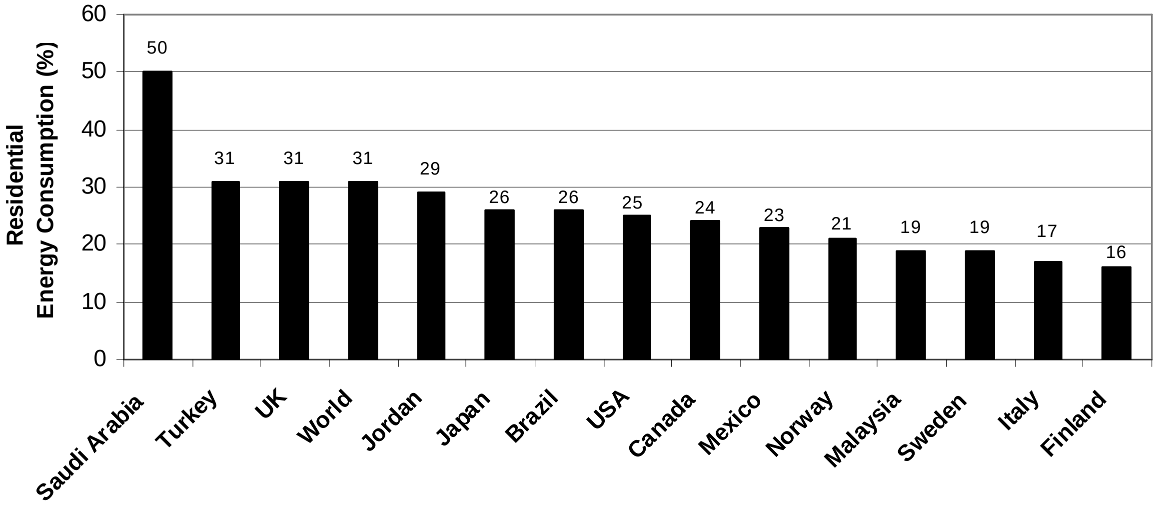

Figure 2. Percent residential energy consumption for various countries (modified from: Saidur, R., Masjuki, H.H., Jamaluddin, M.Y.(2007). An application of energy and exergy analysis in residential sector of Malaysia. Energy Policy 35, 1050–1063).

As an example, one can look at the European Union. Their energy use in buildings is 40% while their CO_2 emissions are accounting for 36%. Their targets as stated in the EU Climate and Energy Objectives are to reduce both energy consumptions and greenhouse gas emissions by 20% each (WBCSD, 2010). Many are hopeful that sustainable buildings can make a major contribution to tackling climate change and energy use. Of course, this is not something easy to manage unless we properly deal with the energy sources and systems. It will evidently require exergy as a potential tool for true analysis, design, assessment, and performance improvement. This is nicely illustrated in Figure 3 based on the primary goals as listed in Section 1. Exergy then becomes a primary prerequisite to achieve those seven pillars for sustainable buildings.

Figure 3. Exergy as a key player to achieve seven main pillars for buildings.

3. Exergy and Buildings

Thermodynamic principles basically govern energy use and, therefore, an understanding of thermodynamic aspects of energy can help us understand pathways to sustainable development. The impact of energy resource utilization on the environment and the achievement of increased resource-utilization efficiency are best addressed by considering exergy. The exergy of an energy form or a substance is a measure of its usefulness or quality or potential to cause change and provide the basis for an effective measure of the potential of a substance or energy form to impact the environment. It is important to mention that in practice a thorough understanding of exergy and the insights it can provide into the efficiency, environmental impact and sustainability of energy systems, are required for the engineer or scientist working in the area of energy systems and the environment. During the past decade, the need to understand the linkages between exergy and energy, and environmental impact has become increasingly significant (Dincer and Rosen, 2004; 2005; 2007). So, we consider exergy as the confluence of energy, environment and sustainable development and illustrated this in a triangle in Figure 4. The basis for this treatment is the interdisciplinary character of exergy and its relation to each of these disciplines. Furthermore, some earlier studies (e.g., Dincer and Rosen, 2005) indicated that some environmental effects associated with emissions and resource depletion can be expressed based on physical principles in terms of an exergy-based indicator. It may be possible to generalize this indicator to cover a comprehensive range of environmental effects, and research in line with that objective is ongoing.

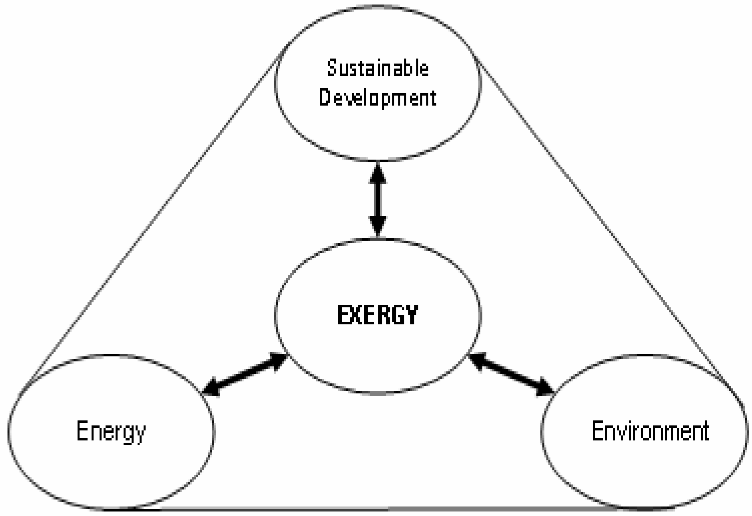

Figure 4. The interdisciplinary triangle of exergy.

The relation between exergy, sustainability and environmental impact is illustrated in Figure 5. There, sustainability is seen to increase and environmental impact to decrease as the exergy efficiency of a process increases. The two limiting efficiency cases in Figure 5 appear to be significant:

- As exergy efficiency approaches 100%, the environmental impact associated with process operation approaches zero, since exergy is only converted from one form to another without loss (either through internal consumption or waste emissions). Also sustainability approaches infinity because the process approaches reversibility.
- As exergy efficiency approaches 0%, sustainability approaches zero because exergy-containing resources (fuel ores, steam, etc.) are used but nothing is accomplished. Also, environmental impact approaches infinity because, to provide a fixed service, an ever increasing quantity of resources must be used and a correspondingly increasing amount of exergy-containing wastes are emitted.

Although in this paper the discussion focuses on the benefits of using thermodynamic principles, especially exergy, to assess the sustainability and environmental impact of building energy systems under exergy concept, this area of work offers many more opportunities for better environment and sustainability as buildings require. There is of course further research opportunity needed to ascertain a better understanding of the potential role of exergy in such a comprehensive perspective. This includes the need for research to (i) better define the role of exergy in environmental impact and design, (ii) identify how exergy can be better used as an indicator of potential environmental impact, and (iii) develop holistic exergy-based methods that simultaneously account for technical, economic, environmental and other factors.

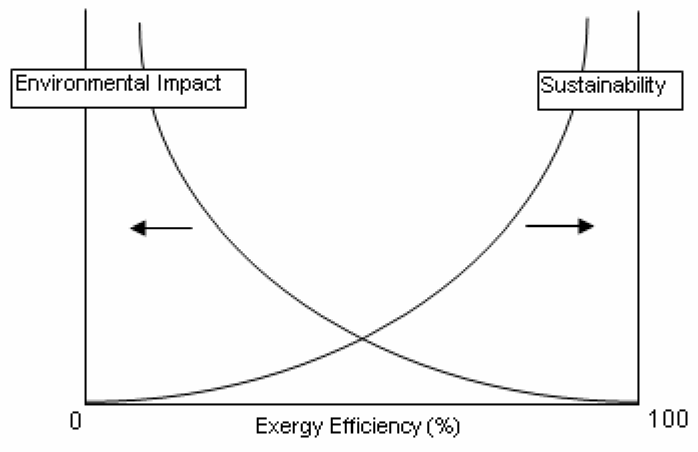

Figure 5. Qualitative illustration of the relation between the environmental impact and sustainability of a process, and its exergy efficiency.

Sustainable development also requires economic viability. Thus, the methods relating exergy and economics also reinforce the link between exergy and sustainable development. The objectives of most existing analysis techniques integrating exergy and economics include the determination of (i) the appropriate allocation of economic resources so as to optimize the design and operation of a system, and/or (ii) the economic feasibility and profitability of a system. Exergy-based economic analysis methods are referred to by such names as thermoeconomics, second-law costing, cost accounting and exergoeconomics. Several detailed reviews of these analysis techniques and applications are available elsewhere (Dincer and Rosen, 2007). Consequently, although there is a diversity of choices about the use of energy options, ranging from fossil fuels to renewable energy sources and hydrogen, available for buildings, it is evident that exergy can only play a crucial role in the context of sustainable buildings to achieve seven main pillars as given in Figure 3.

4. Sustainability and Buildings

A secure supply of energy resources is generally agreed to be a necessary but not sufficient requirement for development within a society. Also, sustainable development demands a sustainable supply of energy resources. The implications of these statements are numerous, and depend on how sustainable is defined. One important implication of these statements is that sustainable development within a society requires a supply of energy resources that, in the long term, is readily and sustainably available at reasonable cost and can be utilized for all required tasks without causing negative societal impacts. Furthermore, supplies of such energy resources as fossil fuels (coal, oil, and natural gas) are generally acknowledged to be finite; other energy sources such as solar, wind, geothermal and hydro are generally considered renewable and therefore sustainable over the relatively long term. Wastes (convertible to useful energy forms through, for example, waste-to-energy production facilities) and biomass fuels are also usually viewed as sustainable energy sources. A second implication of the initial statements in this section is that sustainable development requires that energy resources be used as efficiently as possible. In this way, society maximizes the benefits it derives from utilizing its energy resources, while minimizing the negative impacts (such as environmental damage) associated with their use. This implication acknowledges that all energy resources are to some degree finite, so that greater efficiency in utilization allows such resources to contribute to development over a longer period of time, i.e., to make development more sustainable.

Even for energy sources that may eventually become inexpensive and widely available, increases in energy efficiency will likely remain sought to reduce the resource requirements (energy, material, etc.) to create and maintain systems and devices to harvest the energy, and to reduce the associated environmental impacts.

The first implication, clearly being essential to sustainable development, has been and continues to be widely discussed for buildings and their sustainability since it is now even more significant than before to switch to renewable for applications. The second implication, which relates to the importance and role of energy efficiency in achieving sustainable development, is somewhat directly related exergy and its use as a potential.

It is clear that sustainable development demands a sustainable supply of energy resources that, in the long term, is readily and sustainably available at reasonable cost and can be utilized for all required tasks without causing negative societal impacts.

Renewable energy systems can contribute significantly to meeting society's desire for more efficient, environmentally benign energy use and for sustainable development of the society, particularly in the areas of building heating and cooling and electric power generation. Renewable energy resources and technologies are a key component of sustainable buildings for following reasons:

- Renewable energy resources generally cause less environmental impact than other energy sources for the buildings. So, they make buildings "green", also, the variety of renewable energy resources provides a flexible array of options.
- Renewable energy resources cannot be depleted. If used carefully in the buildings, they can provide a reliable and sustainable supply of energy almost indefinitely for the buildings. So, buildings reach the sustainable position.

Not all renewable energy resources are inherently clean in that they cause no burden on the environment in terms of waste emissions, resource extraction or other environmental disruptions.

Nevertheless, the use of renewable energy resources almost certainly can provide cleaner and more sustainable buildings (Dincer and Rosen, 2007). As an illustration here, Figure 6 shows a wide range of renewable energy options for buildings and their utilization.

Of course, they need to be an integral part of a big picture to cover all what buildings require as heating, cooling and electricity. Of course, it is now even more important to work on multi-generation options to include heat, cooling and electricity production.

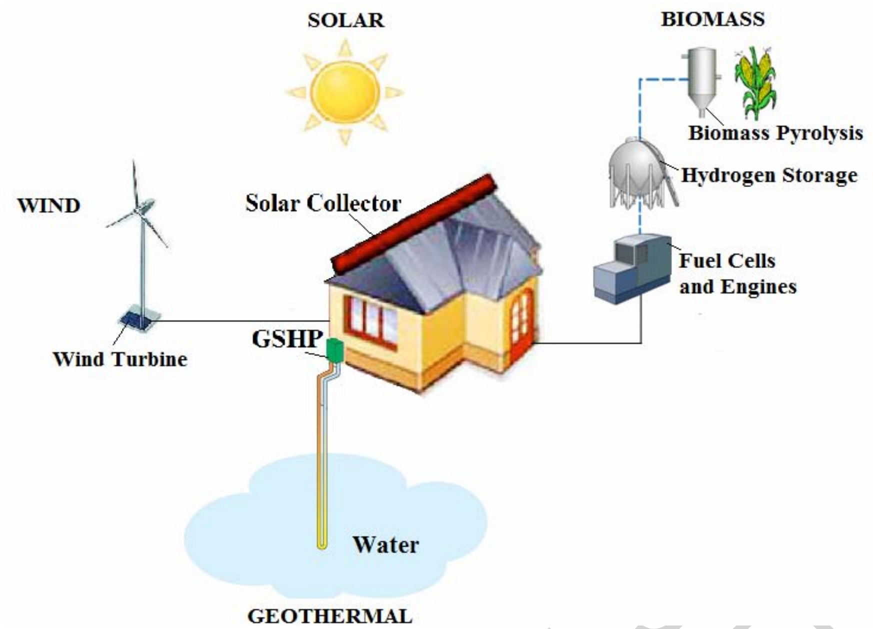

Figure 6. Renewable energy options to achieve sustainability for buildings.

Sustainability often leads local and national authorities to incorporate environmental considerations into energy planning. The need to satisfy basic human needs and aspirations, combined with increasing world population, will make the need for successful implementation of sustainable development increasingly apparent. Various criteria that are essential to achieving sustainable development in a society follow (Dincer and Rosen, 2005):

- information about and public awareness of the benefits of sustainability investments,
- environmental education and training,
- appropriate energy and energy storage strategies,
- availability of renewable energy sources and cleaner technologies,
- a reasonable supply of financing, and
- monitoring and evaluation tools.

This now gives a comprehensive picture about how sustainable buildings can be achieved. It is definitely a multi-dimensional, integral one, covering energy, environment and sustainability as they need to be treated under exergy.

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Biographical Sketch

Ibrahim Dincer is a full professor of Mechanical Engineering in the Faculty of Engineering and Applied Science at University of Ontario Institute of Technology (UOIT) in Canada. Renowned for his pioneering works he has authored and co-authored several books and book chapters, over 450 refereed journal and conference papers, and numerous technical reports. He has chaired many national and international conferences, symposia, workshops and technical meetings and is the founding chair or co-chair of various prestigious international conferences. He has delivered over 150 keynote and invited lectures. He is an active member of various international scientific organizations and societies, and serves as editor in-chief (for International Journal of Energy Research by Wiley and International Journal of Exergy and International Journal of Global Warming by Inderscience), associate editor, regional editor and editorial board member on various prestigious international journals. He is a recipient of several research, teaching and service awards, including the Premier’s research excellence award in Ontario, Canada in 2004. He has made innovative contributions to the understanding and development of exergy analysis of advanced energy systems for his so-called: five main pillars as better efficiency, better cost effectiveness, better environment, better sustainability and better energy security. He is the chair of a new technical group in ASHRAE, named Exergy Analysis for Sustainable Buildings.