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MULTIDISCIPLINARY APPROACHES TO SUSTAINABILITY



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INTRODUCTION

Sustainability has been getting attention in theory and practice particularly for the last two decades. It can be easily seen that using sustainability as a term in books increased after 1987 according to the search results in the Google Ngram Viewer. In this year the World Commission on Environment and Development (WCED) published its Brundtland Report entitled “Our common future”. The report seems affected researchers in this field. When doing the same search for the dimensions of sustainability, it can be clearly seen that while the ecological and environmental sustainability dimension is the most emphasized, the social sustainability is the least emphasized dimension in books. When we performed the same search via Scopus subject database, ‘Business, management and accounting’ and ‘Economics, econometrics and finance’ subject areas constitute approximately 21% while ‘social sciences (27.4%), engineering (20.7%), energy (11.7%) and environmental sciences (32.2%)’. The same search also showed that environmental sustainability concept is quite dominant in the book literature compared to the social and economic sustainability.

Sustainable development and environmental protection are closely related to each other. In fact, environmental protection initiatives have opened the pathway to the sustainability initiatives. The first international initiative in this area was the 1972 United Nations Conference on the Human Environment, in Stockholm, Sweden with the purpose of bringing the industrialized and developing nations together to emphasize the rights of people to a healthy and productive environment (Declaration of the United Nations Conference on the Human Environment, 1972). Another international attempt followed this conference was the establishment of the World Commission on Environment and Development (WCED) tasked by the Secretary General of the UN, in 1983, to overview critical environmental and development problems around the world and formulate realistic proposals to address them. The so called Brundtland Report prepared by this commission and titled as “Our Common Future” was published in 1987 (UN Website). This report emphasized some points for sustainable development on a global level and at the same time brought the concept of sustainability into the foreground on an international level. The UN Conference on Environment and Development (UNCED) in Rio de Janeiro in 1992 was a big success and an agenda, called Agenda 21, was adopted (Rio Declaration on Environment and Development, 1992). Agenda 21 recognized each nation’s right to pursue social and economic progress and assigned to States the responsibility of adopting a model of sustainable development. Kyoto Protocol adopted in 1997 with an environmental focusing entered into force in 2005 as an important success for sustainable development (UN Website, Kyoto Protocol, 2012).

Global warming within the last thirty years became an important problem for the world and its relationship with the greenhouse gases is well known. Almost all the anthropogenic activities result in releasing carbon dioxide, the most dominant greenhouse gas, into the atmosphere. These emissions are mainly related to the consumption of energy produced from fossil fuels. The facts that infrared radiation is trapped by the greenhouse gases and particles in the atmosphere and that the atmospheric carbon dioxide level has increased by some 25% since 1850 mainly due to fossil fuel combustion and land use changes are well accepted (Schneider, 1990; Hartmann et al., 2013). It has been reported that approximately 95% of global warming is related to increasing human activities and so increasing greenhouse gas concentrations (Hartmann et al., 2013; IPCC, 2006; National Research Council, 2010).

Among the international conferences held about this problem, United Nations Framework Convention on Climate Change was a very significant step in 1994 and has been accepted by 197 countries (UN Website). The most comprehensive agreement became the Kyoto Protocol entered into force in 2005 and currently accepted by 191 countries and 1 regional economic integration organization (UN Website, Kyoto Protocol, 2012). Following this agreement, another convention was held in Paris in 2015 with the aim of strengthening the global response to the threat of climate change by keeping a global temperature rise this century well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius (UN Website). The Paris Agreement entered into force in 2016 and currently ratified by 174 countries.

In addition to Global warming problem, water consumption related to anthropogenic activities should also be followed carefully for efficient use of limited fresh water resources in the World. Water is an irreplaceable resource, covering around two-thirds of Earth's surface, although only one percent is available as usable freshwater. Water consumption and pollution can create water shortage especially in some parts of the World. Increased water use and factors such as climate change make water scarcity a Global problem. Water Footprint concept, which is consumed amounts of direct and indirect water for manufacturing of products and services, is a measure developed for efficient water use (Chapagain, Hoekstra, Savenije, Gautam, 2006).

Sustainability concept has a very broad context and is related to many disciplines including politics, education, management, economics, agriculture, architecture, and engineering. Global problems such as climate change, air pollution, soil pollution, water pollution, noise pollution together with decreasing natural resources due to increasing population and consumption forced policy makers to develop some sustainability initiatives as summarized above. In this context, engineering initiatives play an important role in reducing energy and water consumption, increasing renewable energy use, improving production efficiencies and reuse applications, and developing cleaner production technologies.

In accordance with the United Nations sustainable development initiatives, some national and organizational attempts have been made. One early action came from the Swiss State Secretariat for Economic Affairs (SECO) after the Rio Conference in 1992 and 11 Cleaner Production Centers (CPCs) were financed in Africa, Asia, and Latin America. This action has started with focusing on awareness raising, training, information and “good housekeeping” measures and continued with shifting the focus on transfer of environmentally sound technologies combined with financial services such as those offered by international environmental treaties (Grutter and Egler, 2004). The idea behind CPCs was declared as producing goods and services at the same or even better quality with less resources and less pollution. Obtained results indicated that, although cleaner production is an important component, it would not lead to a measurable and sustained improvement of the environment unless integrated with well-managed technology change linked with financial instruments and complemented with social accountability (Grutter and Egler, 2004).

Another important attempt in this area came from the European Union in 2008 with the European Commission’s Sustainable Consumption and Production and Sustainable Industrial Policy Action Plan. Considering that production and consumption have strong impact on pollution, global warming, natural resource depletion and waste formation, the Commission identified priorities which fall into three broad categories as smarter consumption, cleaner production, and global action (Nash, 2009). Although important initiatives have been made and some successes have been obtained in these priority areas, it has been emphasized that since much of the action plan rely on voluntary agreements and indicative thresholds, decoupling economic growth from resource use, which is the fundamental objective of the action plan, requires mandatory quantifiable targets and deadlines (Nash, 2009).

Some national actions to promote industrial symbioses and eco-industrial parks for improving industrial ecology have been taken in some countries. The idea of industrial ecology is to reduce raw material and energy use by utilizing waste, by-products, and waste energy to reduce emissions and waste generation (Korhonen and Snakin, 2003). It has been pointed out in a review article that industrial symbioses tend to develop through spontaneous action of economic actors for economic profit in many examples although designing and promoting these initiatives via policy instruments can also be achieved (Lehtoranta, Nissinen, Mattila, and Melanen, 2011). However, this article also suggested that instead of forcing industries and companies for symbiosis-like arrangements, indirect encouragement of symbiosis with some incentives, such as land use regulation and planning, might be more effective. As a largest manufacturer of products in the world, China has also taken some actions for sustainable production mainly by two regulations: Cleaner Production Promotion Law (2003, 2012) and Circular Economy Promotion Law (2009). Specific research efforts in many countries are going on to develop sustainable processes such as production of biofuels from industrial waste (Foukis et al., 2017; Barik and Murugan, 2015) and production of hydrogen from renewable and sustainable sources

(Chaubey, Sahu, James, Maity, 2013). In addition, attempts to reduce greenhouse gas emissions from cities by sustainable applications such as promoting district heating, using forestry waste as fuel, biogas production from household waste, using photovoltaic cells on roofs, promoting urban farming for families, and using geothermal energy for heating have been made.

In this perspective, this book has three chapters as Sustainable management, Measurement of sustainability, and Environmental sustainability. The title of the first article is “Reviewing Sustainability Awareness Studies by Content Analysis” written by Ayşe Demirhan, Serdar Bozkurt, Mehmet Çağlar, Burcu Yigit. The authors reviewed sustainability awareness studies in the world’s few databases (Ebsco, Springer, Science Direct, Taylor & Francis, Google Scholar) with open access to content analysis. According to their results of content analysis, education and environment areas seem to be at the forefront of sustainability awareness subject.

The second article in this chapter is “The Visual Perception of Corporate Sustainability and Its Dimensions” written by Özlem Tuna, Mustafa Nuri Ural. They conducted to determine the visual perception of corporate sustainability, and its three dimensions; social sustainability, environmental sustainability and economic sustainability. According to their results, the most common objects are biodiversity related objects which are shown as plants or animals. The next most frequent object category is human/people which shows itself as human figures or human hands.

The second chapter, Measurement of Sustainability, include two articles. The first one is “A Balanced Scorecard Approach and a Model Proposal for Institutional Sustainability Measurement” written by Gülşe Yılmaz, Mehmet Nuri Inel and the second one is “Sustainability Performance Analysis of East Black Sea Project (DOKAP) Cities by Using TOPSIS Method” written by Ahmet Sefa Bir, Özgür Çakır.

Yılmaz and Inel aimed to determine the sustainability performance of the scorecard pattern for companies. Its performance reports have been examined. It has been found that there are no key performance indicators in the studies and it is more superficial. The model in the study is a detailed model that includes key performance indicators. This study analyzed the company’s sustainability performance with the BSC model.

Bir and Çakır designed their study to examine the sustainability performances of East Black Sea Project (DOKAP) cities and to compare the sustainability performances of these cities in terms of economic, environmental and social dimensions. The TOPSIS method which is one of the best multi-criteria decision making methods is utilized for the analysis. In this study, it was observed that economic indicators have a high impact on the results.

The last chapter, Environmental Sustainability, includes. In this chapter include “Energy Transition, Climate Change Mitigation and Sustainability” written by Tanay Sıtkı Uyar,

“Identification and evaluation of applicable technologies’ energy scenarios of a big scale building” written by Hatice Sözer, Ergin Kükrer, Utku Simitli, “Effect of Non-Uniform Wake on the Exergy Efficiency Calculations for Wind Turbines” written by Emre Alpman, and “Performance Evaluation of Refrigerants Used in a Flash-System Refrigeration with Regarding to Environmental Aspects” written by Ebru Mançuhan, Barış Yılmaz, M. Kemal Sevindir, Deniz Yılmaz.

Sözer et al discussed the effect of different technologies, configurations and their control scenarios during the integration process in a big scale building based on their energy performance. Results of the study revealed that within the integration of presented scenarios, more than 10% energy saving in annual energy consumption can be obtained which leads to 141,638 kg CO₂ emission reduction.

Alpman investigated the effect of the non-uniform wake on the exergy efficiency calculations for small scale wind turbines. Performance predictions are made for a model small scale horizontal and vertical axis wind turbines using a steady and an unsteady methodology. The results presented show the necessity of using a multi-parameter multi-objective optimization procedure to obtain a suitable aerodynamic design for sustainable wind energy production.

Mançuhan et al. described a flash-system implemented in EES in order to examine the effect of different operating parameters on the system performance. In addition, in order to realize an environmentally friendly refrigeration flash-system both natural (NH₃ and R290) and synthetic (R134a and R404A) refrigerants are examined. An environmental sustainability analysis has been performed for the leakage of refrigerants in terms of ODP and GWP for all studied refrigerants.

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Part 1

SUSTAINABLE
MANAGEMENT

1

REVIEWING SUSTAINABILITY AWARENESS STUDIES BY CONTENT ANALYSIS

Ayşe Demirhan, Serdar Bozkurt, Mehmet Çağlar, Burcu Yiğit

Abstract

The main purpose of this study is; reviewing sustainability awareness studies in the world's few databases (Ebsco, Springer, Science Direct, Taylor & Francis, Google Scholar) with open access to content analysis. In this way, it will be possible to have an idea of the direction of the development of the articles/proceedings on this concept in the international literature. It will also be possible to identify gaps in issues of sustainability awareness that are less relevant in the literature. In this study, content analysis was used as a data analysis technique. According to the results of content analysis education and environment areas seem to be at the forefront of sustainability awareness subject. In addition, Malaysia and the USA have been relatively more prominent in this area. In the studies carried out in this context, depending on the nature of this work; descriptive statistics, content analysis, and graphics visualization determined to be used as data analysis, techniques. However, it should not be overlooked that this research is restricted to only the databases examined. At the same time, the research is considered as a pioneering study on sustainability awareness.

Keywords: *Sustainability, Sustainability Awareness, Content Analysis*

1. Introduction

One of the most important problems in today's world is creating awareness of sustainability on the basis of individuals, institutions, and countries. This process can be seen as the key to the transfer of a sustainable structure to future generations. This key is a key process starting from individuals, to organizations and social institutions to develop sustainable environment, education, economic structure, and so on. This process will enable increased efforts towards sustainability awareness. In this framework, it is important to see the development of studies and efforts in the academic field and to show the direction of the efforts in this direction. In this respect, firstly the concepts of sustainability and sustainability awareness are explained in the study. Then, a relevant literature search was conducted. In the research section, content analysis was carried out for the research in different databases. In the last part, the findings of the study were mentioned and the study was finalized with suggestions and discussion.

The concept of sustainability awareness; can be defined as all of the activities carried out in order to gain awareness and sensitivity towards the environment, to provide motivation in increasing values toward environment, to improve individuals' perspective on global environmental problems, and make them to understand that they are part of the natural environment (Erdoğan & Tuncer, 2009). Sustainability awareness aims to raise awareness of individuals in climate change and global warming issues and to change their attitudes and behaviors in order to ensure that the natural environment is sustainable (Hamid et. al, 2017).

2. Literature Review

With the climate and environmental changes, also global warming in the world, sustainability has emerged recently as an important phenomenon. Resources of the world are about to be exhausted. This situation threatens the existence of human beings on earth. It has become important to think both for the present and the future at the same time. When satisfying the need of today's societies, the needs of tomorrow's societies are also requisite (Lozano, 2008:1840).

Sustainability is undoubtedly one of the most significant concepts of the 21st century (Dyllick, Hockerts, 2002:130; Engin, Akgöz, 2013:86). The importance of sustainability increases day by day. Sustainability has become a popular topic for different disciplines such as architecture, health, ventilation, air conditioning, electricity, plumbing (Rezgui, Wilson, Li, 2004:150). Regardless of discipline, thinking for future generations and preserving the natural environment concurrently, have to be mandatory. In the past, only financial expectations were important for organizations. Based on the fact that the basic human needs such as foods, shelter, and security have not fulfilled in societies and countries, the environmental sustainability is often neglected but today, financial and social expectations that are protecting the environment and social order are together matters of concern (Lozano, 2008:1838).

The extant literature is bound of a variety of definitions regarding the concept sustainability, developed by different researchers and organizations. The reason for this lack of consensus and variety of definitions on the topic of sustainability is that sustainability is influenced by many factors. Some of those factors are limited resources, excessive carbon dioxide emission levels, threats to global warming and climate change (Warren-Myers, 2012). The framework of this study is based on the definitions of Eckstein and Throgmorton (2003). Eckstein and Throgmorton (2003) have underlined the difficulty to balance the concepts of sustainability, economic growth, environmental health and social justice. Huetting & Reijnders (1998) defines sustainability as a vital function of biophysical transformation that will continue forever (Huetting & Reijnders, 1998). From another point of view, sustainability can also be considered as a continuous learning process in which stakeholders actively participate in searching new opportunities. In order to ensure sustainability, one must challenge his/her own

thoughts in unconventional ways reflect this query on his/her current decisions. Adopting new behaviors to avoid future socio-economic problems is probably the most important practice to ensure sustainability (Francis, 2017). In line with this, Burke and Gaughran (2007) emphasize the nature of sustainability as a composition of social, environmental and economic practices in a company (Burke & Gaughran, 2007).

In order to develop such multifaceted practices; organizations need to have an awareness concerning the importance of sustainability. So, sustainability awareness becomes an important theme in organizational behavior literature. The sustainability awareness can be measured by using information and first-hand data. This measurement at this stage can be defined by how stakeholders in sustainability awareness perceive this concept, why and at which level. (Chou & Chou, 2012). Although the term of sustainability is well understood by the experts, the society still lacks sufficient understanding regarding this term. This insufficiency leads confusion towards sustainability. Thus, there is a difference for the meaning of sustainability awareness between industry and public. Sustainable development requires the participation of all members of the community (Garbie, 2015).

To create the awareness for environmental sustainability, two perspectives were identified in relation to behavioral change. First, increasing the public knowledge on the topic in addition to developing an appropriate attitude are crucial. Second, individuals have to review their choices and act according to their needs, knowledge, and awareness (Hamid, et. al., 2017:475). Only being the consumer is not sufficient for this century. Individuals have to be both sensitive and responsible for their environment when producing and consuming goods and services. In this situation, educators have to take responsibilities either (Herremans & Reid, 2002: 16). In addition to the education, organizations have to operate giving an importance to economic, social and environmental dimensions. To provide the sustainability, it is necessary to consider the environment, society, and economy altogether (Lozano, 2008:1839). Organizations should consider the environmental issues while keeping their productivity for the sustainability. If organizations are aware of sustainability, their conscious consumer also will share this awareness with others. As a result, the sustainability awareness will increase gradually. The research questions discussed in the study are as follows;

- What are areas of sustainability awareness studies most commonly associated with?
- How is the distribution of studies on sustainability awareness according to countries?
- In what period are the studies on sustainability awareness concentrated?
- What are data collection tools used in studies on sustainability awareness?
- What are data analysis techniques used in studies on sustainability awareness?
- Generally in which magazines sustainability awareness studies have been published?

Up to this part, the development of the research problem has been mentioned. The next section will discuss the methodology, the population, and the sample, the findings, and interpretations of how the study answers the research problem.

3. Methodology

In this study, content analysis was used as a data analysis technique. Content analysis is a research technique in which valid findings from the relevant text are presented as a series of procedures. The most important feature of it is that it should be systematic and impartial (Koçak & Arun, 2006). Content analysis; is a systematic and repeatable research technique in which certain sentences or words of the text are identified by smaller content categories in the context of the codes formed on the basis of certain rules (Büyüköztürk, et.al., 2012).

On the basis of content analysis; investigated concept, subject, access to the data related to theme could be mentioned. Depending on this access, it is important to make operational definitions of the obtained concepts and then to distinguish them on the basis of themes by sorting the concepts. In this context, the data can be defined through content analysis, and important and hidden facts in the content of data are tried to be extracted. While making different definitions of content analysis, all the definitions come to an agreement that this method must be objective and systematic (Yıldırım & Şimşek, 2016).

In content analysis implemented similarly to the method applied by Göktaş et al. (2012). Before implementing content analysis, firstly, the concept of sustainability awareness has been defined as a scanning and selection criterion. Then, an article/proceeding pool was prepared using the related databases. The relevant concept was examined in terms of field, country distribution, period, data collection tool and analysis technique, journal criteria. Subsequently, data were obtained by arranging similar codes by the researchers from the data pool created by taking into consideration the criteria in the content analysis. These data were then expressed as frequencies and ratios (Göktaş, et.al, 2012).

In accordance with the research aim, 15 articles/proceedings on sustainability awareness with open access have been reached. The research was conducted in 5 open access databases, including Ebsco, Springer, Science Direct, Taylor & Francis, Google Scholar. In this context, 15 articles related to sustainable awareness have been reached in these databases.

4. Findings and Comments

When the distribution of the articles and proceedings reviewed within the scope of the research is examined; it is seen that articles/proceedings are published mostly in the fields of environment and education. There have been 6 (%40) publications in each of these two areas.

Education and environment areas seem to be at the forefront of sustainability awareness subject in the direction of expectations. Following these issues, studies in Art & Industrial Design, Civil Engineering-IT and Economy are followed by 1 (6.7%) publications (Table 1).

Table 1. Distribution of the articles/proceedings by fields of study

Field of Study	f	%
Environment	6	40
Education	6	40
Art & Industrial design	1	6.67
Civil engineering-IT	1	6.67
Economy	1	6.67

When the distribution of the publications by countries is examined, there are 3 (%20) publications from Malaysia, 2 (%13.3) from USA, Turkey and each of the other countries follows them with 1 (%6.7) study. (Table 2)

Table 2. Distribution of the articles/proceedings by countries

Countries	f	%
Malaysia	3	20
USA	2	13.3
Turkey	1	6.67
India	1	6.67
Kyrgyzstan	1	6.67
Finland	1	6.67
United Kingdom	1	6.67
Oman	1	6.67
France	1	6.67
Australian	1	6.67
Lithuania	1	6.67
Brazil	1	6.67

When the distribution of the articles/proceedings related to sustainable awareness subject is examined, 3 (%20) studies were published in 2010. This is followed by 2 (%13.3) papers published in each 2008, 2015 and 2016. It seems that in 2017 and each of the other years has 1 (%6.7) publication. (Table 3). It can be understood from here that most of the studies related to sustainable awareness were carried out in 2010 and then 2008, 2015 and 2016 by years.

Table 3. Distribution of the articles/proceedings by years

Years	f	%
2017	1	6.67
2016	2	13.33
2015	2	13.33
2014	1	6.67
2012	1	6.67
2011	1	6.67
2010	3	20
2009	1	6.67
2008	2	13.33
2007	1	6.67

The survey method was used as data collection tool for articles/proceedings related to sustainability awareness. In addition, when analyzing the distribution of data analysis and data representation of these articles/proceedings, it is seen that descriptive statistical analyzes and content analysis are ranked first with 3 (%30) of each data analysis techniques. Then the graphical representation of the data comes with 2 (%20) of each data analysis techniques. There is 1 (%10) study analyzed by AHP and 1 (%10) study analyzed by fuzzy logic. (Table 4). As it can be seen from this table, it has been determined that in recent years, multi-criteria decision-making methods such as AHP and fuzzy logic have started to be used in the field of sustainability awareness. In this context, it is an inevitable fact that the advanced analysis techniques will also be used in the following years in the field of sustainability awareness.

Table 4. Data analysis techniques and visualization

Data analysis techniques and visualization	f	%
Descriptive statistics (Mean, std. deviation, frequency)	3	30
Content analysis	3	30
AHP	1	10
Fuzzy logic	1	10
Graphics visualization	2	20

When the articles/proceedings related to sustainable awareness published by journals and conferences are examined, *Procedia Social and Behavioral Sciences Journal* 3 (%20) and *Conference proceedings* are in the first place with 3 (%20) studies. However, each of the other international journals which are *Environmental & Science Education*, *Consumers Studies*, *Sustainability in Higher Education*, *Technology Management and Sustainable Development*, *Baltic Journal on Sustainability*, *Moral Education*, *Early Child Development and Care*, *Business and Management and Cleaner Production* has 1 (%6.7) publication. (Table 5).

Table 5. Distribution of publications by journals and proceedings

Journals/Proceedings	f	%
<i>Procedia Social and Behavioral Sciences</i>	3	20
<i>International journal of environmental & science education</i>	1	6.67
<i>International journal of consumer studies</i>	1	6.67
<i>International journal of sustainability in higher education</i>	1	6.67
<i>International journal of technology management and sustainable development</i>	1	6.67
<i>Baltic journal on sustainability</i>	1	6.67
<i>Journal of moral education</i>	1	6.67
<i>Early child development and care</i>	1	6.67
<i>International journal of business and management</i>	1	6.67
<i>Journal of cleaner production</i>	1	6.67
<i>Conference proceedings</i>	3	20

The most important limitation of the study is the examination of only open access articles and proceedings in the relevant databases. For this reason, not all of the databases used worldwide are included in the scope of the study, but rather a few of the most frequently used databases scanning constitutes an important limitation of the study.

5. Conclusion

It is observed that enterprises and individuals in developed and/or developing societies carry out sustainable activities in many areas, mainly environmental issues. It is a known fact that the state of awareness that is being exposed due to a scarcity of resources will lead to significant positive developments both in the present and in the future. In today's conditions where technological developments are experienced rapidly and intensively, it is observed that production and consumption conditions are executed especially by R & D activities in compliance with environmental sustainability consciousness. In addition, besides environmental issues, it is observed that there is certain awareness in the fields of education and health.

In order to see the place of the discourse that is tried to be explained in the outline in the related studies, the studies in the academic literature in different databases were examined in the research. These studies were evaluated in the context of content analysis which is one of the qualitative data analysis techniques. The evaluation was carried out through articles and proceedings with open access.

The results of the content analysis are summarized as follows: In the distribution of the article/proceedings by the related fields, the fields of environment and educational sciences come to the forefront with 6 studies each. Subsequent studies show that there is a multidisciplinary structure. It has been determined that there is 1 study in each field of arts, industrial design and construction-IT and 1 study in economics. As to distribution by the countries, 3 studies in Malaysia and 2 studies in the USA are in the foreground. In 9 studies, the survey was used as a data collection tool. In data analysis, 3 studies were performed content analysis and descriptive statistical analysis (mean, std. deviation and frequency). The studies were mostly published in the *Procedia Social and Behavioral Sciences* (3 articles).

This research can be extended by including the studies in the Web of Science. In the future study, a meta-analysis can be carried out to perform a detailed analysis. In the future studies, by examining the thesis abroad toward human resource practices, cross-country comparative analyses will be possible.

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2

THE VISUAL PERCEPTION OF CORPORATE SUSTAINABILITY AND IT'S DIMENSIONS

Özlem Tuna, Mustafa Nuri Ural

Abstract

This study has been conducted to determine the visual perception of corporate sustainability and its three dimensions; social sustainability, environmental sustainability, and economic sustainability. The images have been gathered from images.google.com on September 2017. Both Turkish and English phrases have been searched and first 50 images on every phrase has been saved as total of 400 images. Then the images are analyzed according to their content. A list has been made for every image to determine the objects that are used. After that, the objects are categorized according to GRI (Global Reporting Initiative) report criteria. A spread sheet program has been used to calculate the frequencies. The results are presented with tables for each category. According to the results the most common objects are biodiversity related objects which are shown as plants or animals. The next most frequent object category is human/people which shows itself as human figures or human hands. The figures that symbolize economic dimension are the least common ones. Other details can be inspected on results section.

Keywords: *Corporate sustainability, social sustainability, environmental sustainability, economic sustainability, cultural differences, visual perception, visual content analysis.*

1. Introduction

Many recent researches have increased the popularity of the concept of corporate sustainability. Companies, society and a growing number of consumers, are now more aware of what corporate sustainability is about (Sukitsch, Engert and Baumgartner, 2015). Particularly corporations have become a key focus of attention in the sustainability issues, since they are perceived to be responsible for many negative impacts on the environment and on societies. Increasingly corporations and their leaders are recognizing the relations and inter-dependences of economic, environmental and social dimension (Lozano, 2013). For businesses, corporate sustainability becomes more a business obligation than greenwashing and branding; high-value global businesses, creating opportunities for business growth, using sustainability to renew their products and services and increase their revenues (Rezaee, 2017). In order to achieve the

vision described by the concept of sustainable development, the contribution of the real sector is defined as corporate sustainability (Bansal, 2005).

Corporate sustainability is seen as an alternative to traditional growth and profit maximization model; its considered as a new and evolving management paradigm. The concept of 'paradigm' is intentionally used. At the same time, corporate sustainability is based on the idea that sustainable development must address social goals such as environmental protection, social justice, equality and economic development. (Wilson, 2003). Most notable definitions and approaches of sustainability, in corporate contexts, refer to the Brundtland Report (1987) and/or are based on the triple bottom line concept with its economic, environmental and social dimensions (Elkington, 1997). Dyllick and Hockerts (2002) framed the three dimensions in the company context as the business case (economic), the natural case (environmental), and the societal case (social) (Engert, Rauter and Baumgartner, 2016).

Corporate Sustainability is the discipline by which companies align decision-making about the allocation of capital, product development, brand and sourcing with the principles of sustainable development, in a resource-constrained world (GACSO, 2011).

In a world economy that is globalized and interconnected by business networks, managers are expected to address sustainability issues in a similar way, not independently. In addition, commitments to sustainable development may vary according to the country's specific historical and cultural background, as well as environmental, social and economic conditions. (Schaltegger et al., 2014). This argument may also be true on the different visual perceptions about "corporate sustainability" of cultures with different languages. Moving from this reality, this paper is aimed at answering the question: what is the visual perception of corporate sustainability and its dimensions? To find the answer to this question the visual objects are categorized according to GRI (Global Reporting Initiative) report criteria. The roof concept is corporate sustainability and economic sustainability, environmental sustainability, and social sustainability are the three dimensions of corporate sustainability. Besides graphs, texts, charts, logos, etc. which could not be categorized under corporate sustainability or its three dimensions are categorized under "Institutional" category.

GRI report helps organizations to set goals, measure performance, and manage change in order to make their operations more sustainable. A sustainability report conveys disclosures on an organization's impacts – be they positive or negative – on the environment, society and the economy. Reporting makes it more concrete and abstract concepts comprehensible while doing this so that sustainable development will support business operations and strategies to understand and manage the impact (GRI, 2013).

The Global Reporting Initiative (GRI) provides a framework for the reporting of the sustainability performances of businesses and organizations (GRI, 2013). There are three dimensions: economic, environmental, social. As can be seen on Table 1 Economic and Environmental

categories do not have sub categories but Social category has four sub categories as Labor Practices and Decent Work, Human Rights (focusing on workers and suppliers/contractors), Society (focusing on communities), and Product Responsibility (focusing on customers).

Table 1. Categories and Aspects in the Guidelines (GRI, 2013)

Category	Economic	Environmental		
Aspects	<ul style="list-style-type: none">• Economic Performance• Market Presence• Indirect Economic Impacts• Procurement Practices	<ul style="list-style-type: none">• Materials• Energy• Water• Biodiversity• Emissions• Effluents and Waste• Products and Services• Compliance• Transport• Overall• Supplier Environmental Assessment• Environmental Grievance Mechanism		
Category	Social			
Sub-Categories	Labor Practices and Decent Work	Human Rights	Society	Product Responsibility
Aspects	<ul style="list-style-type: none">• Employment• Labor/ Management Relations• Occupational Health and Safety• Training and Education• Diversity and Equal Opportunity• Equal Remuneration for Women and Men• Supplier Assessment for Labor Practices• Labor Practices Grievance Mechanisms	<ul style="list-style-type: none">• Investment• Non-discrimination• Freedom of Association and Collective Bargaining• Child Labor• Forced or Compulsory Labor• Security Practices• Indigenous Rights• Assessment• Supplier Human Rights Assessment• Human Rights Grievance Mechanisms	<ul style="list-style-type: none">• Local Communities• Anti-corruption• Public Policy• Anti-competitive Behavior• Compliance• Supplier Assessment for Impacts on Society• Grievance Mechanisms for Impacts on Society•	<ul style="list-style-type: none">• Customer Health and Safety• Product and Service Labeling• Marketing Communications• Customer Privacy• Compliance

It is remarkable that environmental and economic sustainability dimensions are mostly from companies' perspective, the images from social dimension searches reflect not only companies' perspective but also urban development (housing, health and well-being etc.) perspective. Table 2 presents a summary of common aspects that characterize the debate in the urban context. The table was compiled based on a review of selected academic and policy literature, with the ambition of highlighting key aspects, rather than being an all-embracing list (Weingaertner and Moberg, 2014). On 2015 similar results are obtained by an n-gram analysis of the corporate sustainability by the researchers (Ural and Tuna 2015). This research showed that environmental aspects are highly valued by both academicians and field workers.

To understand the concept of "Corporate Sustainability" many different data sources may be used. But after a literature review the researchers did not encounter with any visual data analyze of the concept. Karaağaç (2012:40) emphasis that between five senses almost %83 of all communication is visual. Today with the use of internet visualization has surrounded us. The researchers believe that those big data may have clues about how the society, especially the ones that have been opened to internet, give meaning to the concept "Corporate Sustainability".

Table 2. Social Sustainability: Aspects in the Urban Context (Weingaertner and Moberg, 2014)

Category	Social
Aspects	<ul style="list-style-type: none"> • Accessibility (e.g. access to employment, open spaces, local services, resources) • Social capital and networks • Health and well-being • Social cohesion and inclusion (between and among different groups) • Safety and security (real and perceived) • Fair distribution of income, employment • Local democracy, participation and empowerment (community consultation) • Cultural heritage (e.g. local heritage and listed buildings) • Education and training • Equal opportunities and equity • Housing and community stability • Connectivity and movement (e.g. pedestrian friendly, good transport links) • Social justice (inter-generational and intra-generational) • Sense of place and belonging • Mixed use and tenure • Attractive public realm • Local environmental quality and amenity

2. Methodology

This study has been conducted by two researchers to determine the visual perception of corporate sustainability, and its three dimensions; social sustainability, environmental sustainability and economic sustainability. Özlem Tuna contributed with scientific frame work, image analysis and categorization are. The study is designed by Nuri Ural and he helped on gathering the images, analyzing and representing the quantitative data, and reporting the results.

The images have been gathered from images.google.com on September 2017. Both English and Turkish phrases with the same meaning are googled. There are four English and four Turkish total of eight search phrases. The translations of the Turkish and English phrases are as follow.

Table 3. The Phrases in English and their Turkish Translations

English	Turkish
Corporate Sustainability	Kurumsal Sürdürülebilirlik
Environmental Sustainability	Çevresel Sürdürülebilirlik
Social Sustainability	Sosyal Sürdürülebilirlik
Economic Sustainability	Ekonomik Sürdürülebilirlik

These eight phrases have been searched and first 50 images on every phrase has been saved total of 400 images. The images are numbered to establish a consensus between researchers. Then the images are analyzed according to their content. A list has been made for every image to determine the visual objects that are used on this images. A sample search result can be seen on Figure 1.

Figure 1 - Sample Image Results From “Corporate Sustainability”



After that, the visual objects are categorized according to GRI (Global Reporting Initiative) report criteria. The roof concept is corporate sustainability and economic sustainability, environmental sustainability, and social sustainability are the three dimensions of corporate sustainability. Besides, some visual objects are categorized under institutional category. Environment related objects like sky, plants and green grass, animals etc. are categorized under “Environment” group. Hands, human figures, accommodation figures and buildings and workplace related visual objects are categorized under “Social” group according to GRI. And for “Economic” group visual objects like currency symbols like dollar or euro, money box or coins etc. are categorized. As a last category, graphs, texts, charts, logos, etc. are categorized under “Institutional” group.

After this categorization a spread sheet program has been used to calculate the frequencies. The results are presented with tables for each category. On the tables there are two different presentation style, the bold ones and the regular ones. Bold data should be evaluated among themselves and the regular ones represent the details of the bold typed category and should be evaluated separately. The tables can be seen on results category of this paper.

3. Results

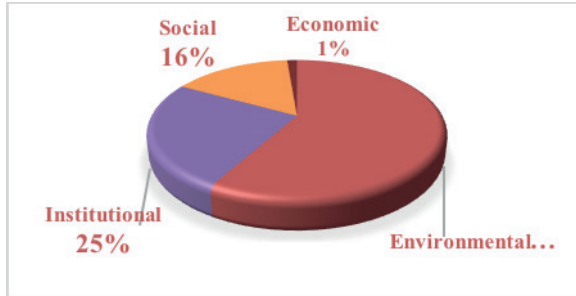
The 400 images from 8 different search phrases contain 1241 different visual objects which are categorized in four different groups. The results have been analyzed using spread sheet programs. The data has been represented with frequencies and percentages.

Table 4. Corporate Sustainability

	English		Turkish	
	Freq.	Percentage	Freq.	Percentage
ENVIRONMENTAL				
Bio Diversity	62	69,66%	44	62,86%
Energy	20	22,47%	8	11,43%
Water	1	1,12%	1	1,43%
Emissions and waste	2	2,25%	1	1,43%
Transportation	3	3,37%	8	11,43%
Materials	1	1,12%	8	11,43%
	89	58,17%	70	51,09%
SOCIAL				
Housing	8	33,33%	3	15,00%
Health	1	4,17%		
Society	15	62,50%	15	75,00%
Employment	-	-	1	5,00%
Education	-	-	1	5,00%
	24	15,69%	20	14,60%
ECONOMICAL	2	1,31%	0	0,00%
INSTITUTIONAL	38	24,84%	47	34,31%
TOTAL	153	100%	137	100%

The results about the search phrase “corporate sustainability” both in Turkish and English can be seen on Table 4. The most common visual object on images are categorized in environmental category. For both languages more than half of the objects are environmental related. Among environmental objects most of them (%70 English -%63 Turkish) are symbolizing bio diversity. Another important result is that a big part (%63 English-%75 Turkish) of social visual objects are Society related. Economy related visual objects are negligible. Other results can be seen on Table 4.

Figure 2. Corporate Sustainability in English Figure



3. Corporate Sustainability in Turkish

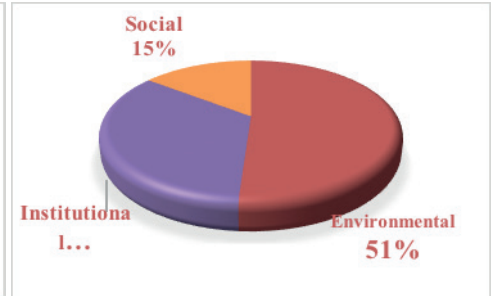


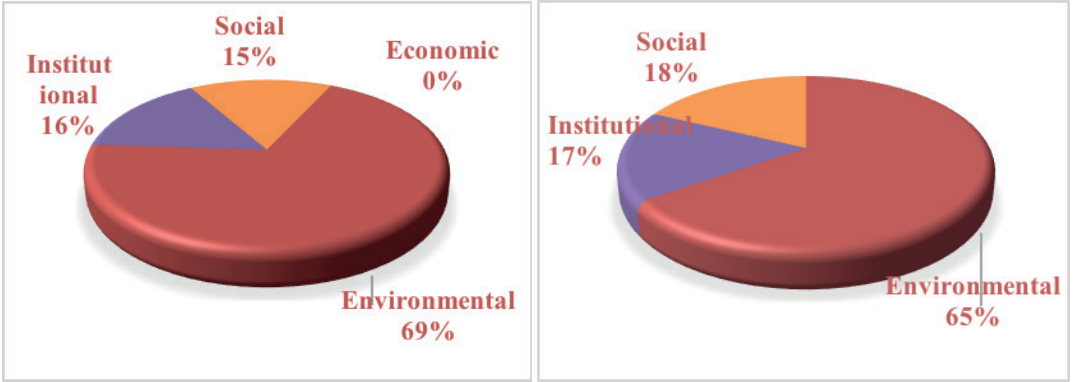
Figure 2 and 3 are showing the graphs for search phrase “corporate sustainability”. It’s worth paying attention to how the graphs are similar. The most common visual objects are Environmental related.

Table 5. Environmental Sustainability

	English		Turkish	
	Freq.	Percentage	Freq.	Percentage
ENVIRONMENTAL				
Bio Diversity	114	74,03%	95	74,22%
Energy	13	8,44%	14	10,94%
Transportation	4	2,60%	11	8,59%
Materials	11	7,14%	0	0%
Emissions and waste	6	3,90%	1	0,78%
Water	6	3,90%	7	5,47%
	154	69,06%	128	65,31%
SOCIAL				
Society	19	55,88%	15	42,86%
Education	1	2,94%	2	5,71%
Employment	3	8,82%	4	11,43%
Housing	11	32,35%	8	22,86%
Health	-	-	6	17,14%
	34	15,25%	35	17,86%
ECONOMICAL	0	0,00%	0	0,00%
INSTITUTIONAL	35	15,70%	33	16,84%
TOTAL	223	100%	196	100%

Table 5 shows the results for the search phrase “Environmental sustainability” both in English and Turkish. Again environmental visual objects are most common (%69-%65), even higher than the other search results because this search is especially related to environment, and among them biodiversity related objects are observed most often (%74-%74). Other results can be seen on Table 5.

Figure 4. Environmental Sustainability in English Figure 5. Environmental Sustainability in Turkish



The graphs for the search phrase “Environmental sustainability” can be seen on figure 4 and on Figure 5. The distributions are very close on both languages. Because the search phrase is directly related to environment the environment group is even higher than the other phrases.

Table 6. Economic Sustainability

	English		Turkish	
	Freq.	Percentage	Freq.	Percentage
ENVIRONMENTAL				
Bio Diversity	47	46	45	70,31%
Transportation	3	5,00%	10	15,63%
Energy	7	11,67%	1	1,56%
Materials	4	4	4	6,25%
Water	-	-	4	6,25%
	60	44,12%	64	43,54%

SOCIAL				
Society	14	82,35%	14	53,85%
Housing	3	17,65%	4	15,38%
Employment	-	-	2	7,69%
Education	-	-	3	11,54%
			3	11,54%
	17	12,50%	26	17,69%
ECONOMICAL	14	10,29%	6	4,08%
INSTITUTIONAL	45	33,09%	51	34,69%
TOTAL	136	100%	147	100%

The results for the search phrase “Economic sustainability” for both English and Turkish can be seen on Table 6. Because this search is directly related to economics it has the highest amount of economical related visual objects among all other searches. It is surprising that, it is still very low comparing other visual object groups. The most common groups are Environmental and Institutional ones as usual.

Figure 6. Economical Sustainability in English

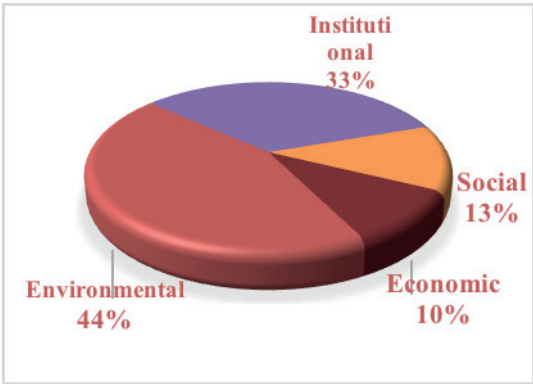


Figure 7. Economic Sustainability in Turkish

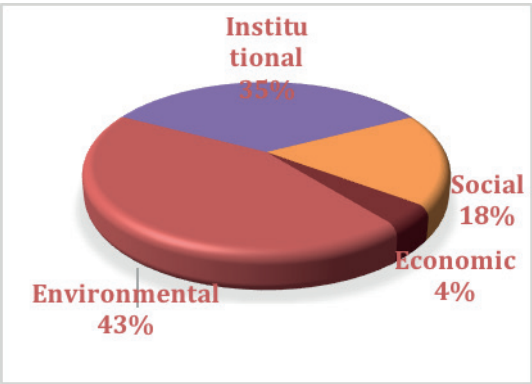


Figure 6 and Figure 7 show graphical results for the phrase “Economical sustainability”. Both languages are very similar. This time economical visual images are beyond negligible but still very low compared to other groups.

Table 7. Social Sustainability

	English		Turkish	
	Freq	Percentage	Freq	Percentage
ENVIRONMENTAL				
Bio Diversity	25	58,14%	49	76,56%
Energy	7	16,28%	4	6,25%
Emissions and waste	3	6,98%	-	-
Transportation	3	6,98%	5	7,81%
Materials	5	11,63%	6	9,38%
	43	37,39%	64	46,04%
SOCIAL				
Education	1	4,17%	-	-
Society	15	62,50%	25	78,13%
Health	4	16,67%	4	12,50%
Housing	4	16,67%	3	9,38%
	24	20,87%	32	23,02%
ECONOMICAL	1	0,87%	1	0,72%
INSTITUTIONAL	47	40,87%	42	30,22%
Total	115	100%	139	100%

Not surprisingly on Table 7 Social visual objects are more frequent than the other search phrases in “Social sustainability”, but still environmental and institutional visual objects are more than social visual objects. Economical visual objects are negligible as usual.

Figure 8. Social Sustainability in English

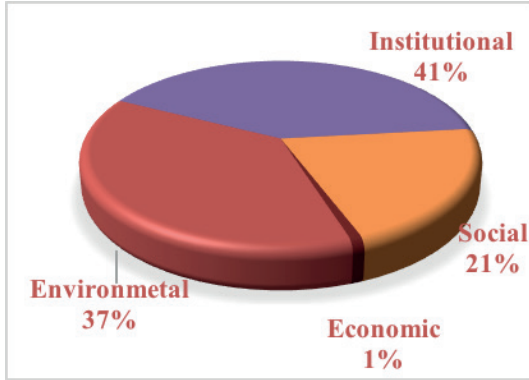
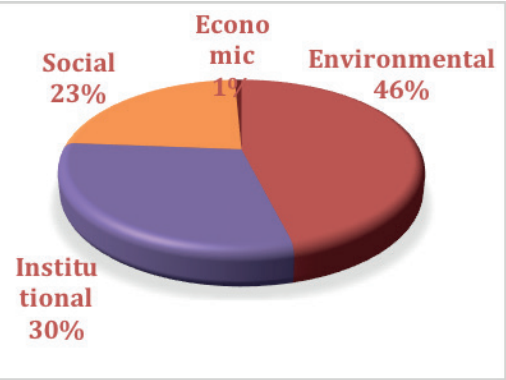


Figure 9. Social Sustainability in Turkish



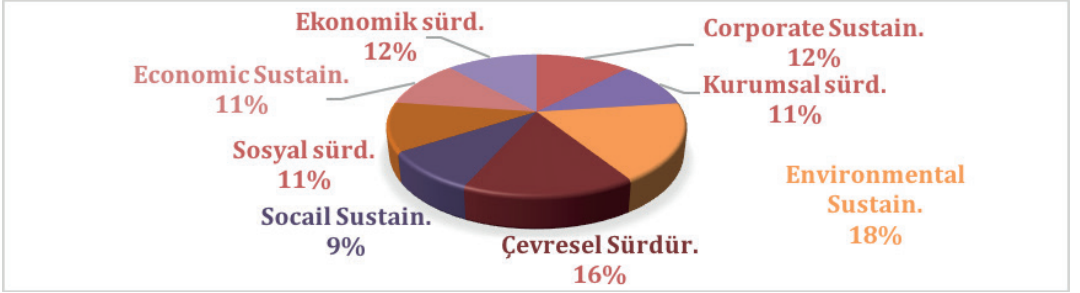
The graphs for “Social Sustainability” both in English and Turkish can be seen on Figure 8 and Figure 9. Although they are very similar on English search results Institutional visual objects are more than the Turkish Counterparts.

Table 8. Total Frequency by Dimensions

	Image Categories				
	Environmental	Social	Economic	Institutional	Total
Corporate sustainability	89	24	2	38	153
Kurumsal sürdürülebilirlik	70	20	0	42	132
Environmental sustainability	154	34	0	35	223
Çevresel Sürdürülebilirlik	128	35	0	33	196
Social sustainability	43	24	1	47	115
Sosyal sürdürülebilirlik	64	32	1	42	139
Economic sustainability	60	17	14	45	136
Ekonomik sürdürülebilirlik	64	26	6	51	147
Total	672 (%54)	212 (%17)	24 (<%1)	333(%27)	1241

Table 8 shows a short abstract of all phrases and their main groups. There are eight phrases, four Turkish and four English that are shown as rows. The images are categorized on four groups which are represented as rows. There are total 1241 visual objects on 400 images. The distributions are quite similar on every category and it fits the total distribution. The details can be found on earlier parts of this paper in result category.

Figure 10. Total by Dimensions



Eight search phrases contain similar quantities of visual objects. Only “Çevresel sürdürülebilirlik” and Environmental sustainability, which are actually the same phrase one in English and the other one in Turkish, have slightly higher visual objects in images. The distributions can be seen on figure 10.

Figure 11. Total by Categories

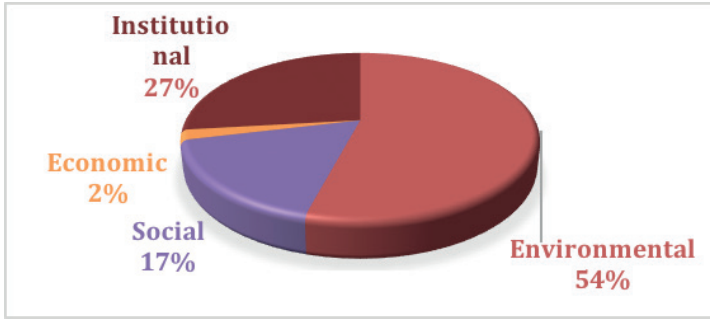


Figure 11 shows a visual presentation for visual object categories on 400 images. These 400 images contain 1241 visual objects and only a small part of them are economical. More than half of them are environmental and the rest are divided into Institutional and Social categories. The details are on figure 11.

4. Conclusion and Discussion

The concept of corporate sustainability is increasingly being analyzed and considered both by academics and practitioners. Despite this, a study for the visual perception of corporate sustainability and its dimensions could not be encountered in literature review. This study is hoped to contribute to the field with data about the visual perception of corporate sustainability and its dimensions in Turkish and English. The online searches have been resulted mostly with images that corporates use to represent themselves. These images contribute on the point of view of corporates and their partners about sustainability.

There are three major conclusions of this study. First of all since Organization for Economic Cooperation and Development (OECD) has been established on 1960, its politic (International Union for Conservation of Nature and Natural Resources – IUCN, 1980; Brundtland Report, 1987) and academic (Shrivastava, 1995; Starik ve Rands, 1995; Elkington, 1997) studies approach the subject from an environmental perspective. Besides the corporate sustainability is related in literature with socio-productivity and eco-productivity (Dyllick ve Hockerts, 2002). It is mentioned that this may only be possible with effective use of natural resources and making it an important part of corporate strategies. The results of our study seem parallel with that. The visual perception of corporate sustainability and its dimensions seem to handle the subject from environmental perspective point of view on both languages, and when compared with other aspects the biodiversity aspect of environment group seem to be more important. However, this may be a good sign for the future of environmental protection, this approach narrows down the meaning of corporate sustainability. Corporate sustainability is a far wider concept than its environmental aspect. Although environmental problems are a real important issue, and should be handled primarily, and although its hope giving that this approach can help to save the world and solve the environmental problems, it still should be considered carefully to not narrow down the original meaning.

Other than this the economic perspective seems to be really low on each eight search phrases used in for this study. This is where the “corporate sustainability” concept is being narrowed. The corporate sustainability is mentioned in literature mostly with its three dimensions, social sustainability, economic sustainability, and environmental sustainability. But not only the results of our study as visual perception of corporate sustainability, but also the researches, and common sense (Ural, Tuna 2015) are also more focused on environmental aspect of corporate sustainability. And in most cases economic aspect of corporate sustainability is neglected. However, this may not directly affect the community badly; the semantic restriction can lead on misinterpretation of the concept which should be considered carefully. Or it could be better to review the meaning of corporate sustainability under these circumstances.

As third there is an important similarity on all phrases and groups between Turkish and English. This similarity is really worth attention. This is a common fact in many areas (Ural, Tuna 2015). Turkey is a developing country and it has strong bonds with western culture. The daily life and living conditions are very similar among many other things. Turkey has changed parallel to the global change and Turkey and western culture get more alike day to day. This may also affect the perception on concepts and corporate sustainability is no exception to this either. Besides the concept of corporate sustainability is transferred from western literature directly. So this may not be surprise at all. Both languages contain a substantial amount of logos, graphs, schemes etc. This may also be an advantage for Turkey because if the similarities are strong enough, the solutions and case studies may be transferred easier to Turkish counterparts. And the results of western researches may be more beneficial.

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Part 2

MEASUREMENT OF
SUSTAINABILITY

1

A BALANCED SCORECARD APPROACH AND A MODEL PROPOSAL FOR INSTITUTIONAL SUSTAINABILITY MEASUREMENT

Gülşe Yılmaz, Mehmet Nuri İnel

Abstract

Today, Norton and Kaplan's balanced scorecard (BSC) model is used to improve enterprise performance. The BSC creates key performance indicators for companies. Companies identify their current status in performance reports and set performance targets for the future with the BSC. These targets have been both a strategy and a sustainability tool for companies. For this reason, there is a need for its performance balanced scorecard in measuring the sustainability performance of companies. BSC will play an active role in determining the sustainability and its strategy. The purpose of this study is to determine the sustainability performance of the scorecard pattern for companies. Its performance reports have been examined. It has been found that there are no key performance indicators in the studies and it is more superficial. The model in the study is a detailed model that includes key performance indicators. In this context, the economic, social, environmental, and institutional profile dimensions of the GRI G4 (Global Reporting Initiative) sustainability reports and the financial, customer, internal processes, learning and development dimensions of the performance scorecard are intertwined. The company's sustainability was analyzed with the BSC model.

Keywords: *Sustainability, Sustainability Report, Balanced Scorecard*

1. Introduction

The concept of sustainability has become the most popular topic today. "Our Common Future" of the Brundtland Commission published in 1987 with the report, sustainability has been influential in almost every field of our lives (Cantimur, 2011). Different definitions have been made by everyone about the concept of sustainability. Sustainability is used in many areas. There are terminological uses such as sustainable development, sustainable agriculture, sustainable cities,

sustainable economy, sustainable architecture and sustainable growth (Yavuz, 2010). This terms are also an indication that sustainability is a common expression among sectors.

For companies; especially the “corporate sustainability” concept is important. Corporate sustainability refers not only to economic sustainability, but also to social and environmental sustainability. Sustainability reports have become widespread with the inclusion of social and environmental issues. Companies share their sustainability activities in public with these reports. Published sustainability reports are generally in the GRI (Global Reporting Initiative, 2014) format. Performance indicators set by the GRI in the formation of reports play a key role. These indicators have brought an international perspective to measurement and evaluation.

Kaplan and Norton’s balanced scorecard to company’s performance strategy is to maintain its position and importance in terms of sustainability. There are four dimensions in the balanced scorecard performance. These are financial, customer, internal processes, learning and development dimensions (Kaplan and Norton, 1992). In this study, BSC and sustainability dimensions were intersected.

2. Literature Review

There are differences in the definitions of sustainability. According to Azapagic and et al, it is to take measures for the future (2003). According to Yelkikalan and Aydın, it is the fulfilment of today’s needs and the effective use of all resources for the future (2010). According to Çamlıca and Akar, it can preserve and sustain its existence (2014). According to Bıçakçı; it is defined as existence (2012). According to Çakar, Filiz and Hacıhasanoğlu, Chaplin and others, a common definition has been sought in sustainability. It has been reported that the correct use of available resources should prevent future generations from being exposed to resource deprivation (Çakar, 2007; Filiz and Hacıhasanoğlu, 2011; Chapin, 1996). Hicks notes that by examining the relationship between income and consumption, sustainability cannot be possible if consumption is high (1962). In achieving corporate sustainability, sustainable development as well as the contribution of institutional economic growth have high precaution. (Wilson, 2003) The first thing that comes to mind when it comes to corporate sustainability is the economy. Corporate sustainability integrates with corporate governance principles. Institutional sustainability is the efficient use of the environmental, economic and social resources that the institution has (Dyllick and Hockerts, 2002). The sustainability activities of the business should support the purpose of existence (Salzmann, 2006).

Today, businesses have included economic, social and environmental issues in their reports. Tietenberg, Tom and Henk Folmer (The International Yearbook of Environmental and Resource Economics, 2006). These reports are referred to as sustainability reports. The aim of sustainability reporting is to open up the business situation by providing transparency to business

stakeholders, investors and the public (Gray et al, 2004). Schaltegger and Herzig have described the benefits of sustainability reporting as value, competitive advantage and strength, corporate reputation, product service, performance enhancement, advantage over competitors, employee satisfaction and development (2011). The reasons for the preference of sustainability reporting are follow-up to targets, the applicability of social and environmental strategies, the sharing of corporate messages with business stakeholders and society, transparency and reliability, stakeholder information, corporate reputation and employee satisfaction (Kolk, 2004).

Sustainability reports have come to the forefront with the addition of economic and economic factors as well as environmental and social factors. There are four outstanding reporting frameworks on sustainability around the world. These reports G4 presented by the Global Reporting Initiative (GRI), Communication on Progress (COP) prepared in accordance with UNGC, Integrated Reporting (IR) prepared by the International Integrated Reporting Council (IIRC) and the Carbon Disclosure Project (CDP). The COP report deals with UNGC's 10 critical human rights issues. COP reports are annual statements issued to stakeholders. The headings of the CDP report are entirely environment related. The IR report links the institution's strategy to sustainability. It is related to vision. It is the fourth version of GRI framework report formats. Social, environmental and economic dimensions, it reveals sustainability. Investors can easily evaluate the sustainability reports in the G4 format prepared by the enterprises. (Borsa İstanbul, 2014). Companies mostly use the G4 standard, which is presented by the Global Reporting Initiative from these reporting frameworks. The reason why GRI G4 is preferred in this study is its widespread use in the world.

Corporate sustainability can be measured with Norton and Kaplan's model that is BSC. BSC is a strategic performance management system (Kaplan and Norton, 2003) BSC is strategic planning and reporting (Gautreau and Kleiner, 2001). BSC is a multi-dimensional organizational performance measurement system (Kaplan and Norton, 2007) According to Norton and Kaplan, the most widespread work that created sustainability as a model with Balanced Scorecard was introduced by White in 2005. In White's work, economic, social and environmental sustainability factors and the four dimensions of BSC, financial, customer, internal processes, learning and development approaches, have been intertwined. The current GRI sustainability report form in 2005 is the GRI report. White reviewed the economic, environmental and social dimensions of the GRI G3 report format and the four dimensions of the BSC and general proceedings (Gwendolen, 2005). The work of White and others is interpreted by Özçelik in 2013. In Özçelik's (2013) study, sustainability has examined the formation process of performance cares. Sustainability performance scorecard is divided into 3 basic steps by Figge et al., 2002. The first of these steps; the selection of strategic business units, the second the determination of environmental and social aspects, and the third the determination of the appropriateness of social and environmental aspects for business unit strategy (Frank et al., 2002).

3. Methodology

In this study, GRI G4 reporting format is used. In addition to other works in the literature, the institutional profile has been added to the economic, social and environmental sustainability dimensions. Specific standard declarations and general standard declarations in the GRI G4 reporting format have been reviewed. (GRI G4, 2014) A total of 110 measurable performance indicators were determined. These indicators are grouped into economic, social, environmental and institutional profiles. 110 indicators were intersected with the four dimensions of the BSC. Intuitive method was used at the intersection of BSC and sustainability dimensions. An overview of the heuristic method at the intersection of BSC and sustainability dimensions:

- Traditional financial measures in financial terms,
- From the customer's perspective the company's value-creation process and non-financial measures,
- Operational efficiency and efficiency measures of company activities in terms of processes,
- On the level of learning and development, the focus is on creating innovative values and organizational value.

The method used in our model is an intuitive method. In this framework, 110 indicators were evaluated and categorized. The intersection of BSC dimensions and sustainability dimensions is intuitive. In similar studies in the literature, it is seen that the intersections are made with the intuitive method. The model has come down to the performance indicator dimension. In the model, 110 quantitative performance indicators of the GRI G4 sustainability reporting format were segmented by BSC dimensions. This separation was made intuitively. It could also be done with other methods. (Expert opinions, questionnaires, focus interviews, etc.). The reason for not using the other methods is that the indicators are available in the GRI G4 report. Partitioning of the indicators is also obvious.

Specific standard declarations and general standard declarations in the GRI G4 reporting format have been reviewed. Performance indicators for special standard declarations are quantitative indicators. Indicators of general standard declarations are qualitative indicators. The issues related to the general standard declarations are related to the institutional profile and are generally risk management and company strategies. Indicators related to specific standards are economic, environmental and social indicators. All models related to specific standards are included. There are 58 indicators in general standard declarations. 4 of these indicators have entered the model.

Data and Model

All indicator sets are in GRI G4 reporting format (GRI, 2014). 4 of the 110 indicators were taken from GRI general standard declarations. 106 indicators were taken from GRI special standard declarations. Main topics in the economic section are economic performance, purchasing practices and market presence. Main topics in the environmental section are materials, energy, water, emissions, waste, products and services, compliance and suppliers. Main topics in the social section are labor practices and decent work, human rights, society and product responsibility. In our model, the performance indicators of the main subjects are analysed. The sustainability performance balanced scorecard model is shown with indicators on the following tables (Table 1-4) (GRI, 2014). The following tables are the intersection of sustainability dimensions and BSC dimensions on the basis of indicators. Table 1 shows the economic dimension of sustainability and BSC intersection. Table 2 shows the intersection of BSC and environmental dimension of sustainability. Table 3 shows the intersection of BSC and social dimension of sustainability. Table 4 shows also the intersection of BSC and institutional profile dimension of sustainability. The codes and names of all the tables are taken from the GRI G4 sustainability report standard. In addition to the main sustainability dimension, sub-dimensions of sustainability have been added. The intersection of the models is specified in the methodology of implementation. The intersection application tactic of the model is stated below:

- Traditional financial measures in financial terms,
- From the customer's point of view, the company's value-creation process and non-financial measures,
- Operational efficiency and efficiency measures of company activities in terms of processes,
- On the level of learning and development, the focus is on creating innovative values and organizational value.

A BALANCED SCORECARD APPROACH AND A MODEL PROPOSAL FOR INSTITUTIONAL SUSTAINABILITY MEASUREMENT

Gülşe Yılmaz, Mehmet Nuri İnel

Table 1. Sustainability Performance Scorecard Economic Dimension

Sustainability Dimension	Indicator (GRI G4 Report Standard)			BSC Dimensions			
	Sub Dimensions	Indicator Code	Indicator Name	Finance	Customer	Processes	Learning
Economical	Economic Performance	G4-EC1	Economic value retained	√			
	Economic Performance	G4-EC3	Estimated value of debt	√			
	Economic Performance	G4-EC3	Percentage of salary contributed by employee or employer				√
	Economic Performance	G4-EC3	Level of participation in retirement plans				√
	Economic Performance	G4-EC4	Financial assistance from the state	√			
	Economic Performance	G4-EC4	Loans	√			
	Economic Performance	G4-EC4	Incentives	√			
	Economic Performance	G4-EC4	Investment grants, research and development grants and other related grant types	√			
	Economic Performance	G4-EC4	Awards	√			
	Economic Performance	G4-EC4	Copyright delays	√			
	Economic Performance	G4-EC4	Financial assistance from Export Credit Agencies (ECA)	√			
	Economic Performance	G4-EC4	Financial incentives	√			
	Market Asset	G4-EC5	Ratio of gender wages to local minimum baseline wages				√
	Market Asset	G4-EC6	Percentage of top management's employment at distinctive operations locations				√
	Purchasing Apps	G4-EC9	Proportion of expenditure on local suppliers at distinctive operation sites	√			

Source. GRI G4. Implementation Handbook, 2014, (p. 23-235)

Table 2. Sustainability Performance Scorecard Environmental Dimension

Sustainability Dimension	Indicator (GRI G4 Report Standard)			BSC Dimensions			
	Sub Dimensions	Indicator Code	Indicator Name	Finance	Customer	Processes	Learning
Environmental	Materials	G4-EN1	Used non-renewable materials			√	
	Materials	G4-EN1	Used renewable materials			√	
	Materials	G4-EN2	Percentage of recycled materials in the manufacture of the primary products and services of the enterprise			√	
	Energy	G4-EN3	Total energy consumption in the organization			√	
	Energy	G4-EN4	Energy consumed outside the organization			√	
	Energy	G4-EN5	Energy intensity ratio			√	
	Energy	G4-EN6	The amount of energy consumption reduction achieved as a direct result of savings and efficiency initiatives			√	
	Water	G4-EN10	Total volume of recycled and reused water			√	
	Emissions	G4-EN18	Greenhouse gas emissions intensity ratio			√	
	Emissions	G4-EN21	NOX significant amount of air emissions, (kilograms or multiples)			√	
	Emissions	G4-EN21	SOX significant amount of air emissions, (kilograms or multiples)			√	
	Emissions	G4-EN21	Persistent organic pollutants (POP) are the amount of significant air emissions, (kilograms or multiples)			√	
	Emissions	G4-EN21	Volatile organic compounds (VOC) are the amount of apparent air emissions, (kilograms and folds)			√	
	Emissions	G4-EN21	Hazardous air pollutants (HAP) amount of significant air emissions, (kilograms or multiples)			√	
	Emissions	G4-EN21	Particulate matter (PM) is the amount of significant air emissions (in kilograms or multiples)			√	
	Wastes	G4-EN23	Total weight of reuse of hazardous and non-hazardous wastes			√	
	Wastes	G4-EN23	Total weight of recycling of hazardous and non-hazardous wastes			√	
	Wastes	G4-EN23	The total weight of recovery, including energy recovery of hazardous and non-hazardous wastes			√	
	Wastes	G4-EN24	Recorded significant metrics and cumulative volume of debris			√	

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Environmental	Wastes	G4-EN25	Total weight of hazardous waste transported			√	
	Wastes	G4-EN25	Total weight of imported hazardous wastes			√	
	Wastes	G4-EN25	Total weight of exported hazardous wastes			√	
	Wastes	G4-EN25	Total weight of treated hazardous wastes			√	
	Products and Services	G4-EN28	Percentage of recycled products and packaging materials for each product cat.			√	
	Coherence	G4-EN29	Total monetary value of significant penalties	√			
	Coherence	G4-EN29	Total number of non-monetary sanctions			√	
	General	G4-EN31	Waste disposal, emission treatment and remediation costs	√			
	General	G4-EN31	Prevention and environmental management costs	√			
	Evaluation of Supplier from Environmental Care	G4-EN32	Percentage of new suppliers surveyed using environmental criteria			√	
	Evaluation of Supplier from Environmental Care	G4-EN33	Number of suppliers subject to environmental impact assessments			√	
	Evaluation of Supplier from Environmental Care	G4-EN33	The number of suppliers found to have existing and potentially adverse environmental impacts at a significant scale			√	
	Evaluation of Supplier from Environmental Care	G4-EN33	Percentage of suppliers who are satisfied with current and potential adverse environmental impacts at a significant scale and who are committed to improvements			√	
	Evaluation of Supplier from Environmental Care	G4-EN33	Percentage of suppliers whose current and potential adverse environmental impacts have not been identified at a significant scale			√	
	Environmental Complaints Mechanisms	G4-EN34	Total number of official complaints related to environmental impacts during the reporting period		√		
	Environmental Complaints Mechanisms	G4-EN34	Number of complaints received during the reporting period		√		
	Environmental Complaints Mechanisms	G4-EN34	Number of complaints resolved during reporting per.		√		
	Environmental Complaints Mechanisms	G4-EN34	Total number of resolutions of complaints filed before the reporting period		√		

Source. GRI G4. Implementation Handbook, 2014, (p. 23-235)

Table 3. Sustainability Performance Scorecard Social Dimension

Sustainability Dimension	Indicator (GRI G4 Report Standard)			BSC Dimensions			
	Sub Dimensions	Indicator Code	Indicator Name	Finance	Customer	Processes	Learning
Social	Labor Practices and Decent Work for Humanity	G4-LA1	Percentage of female employees who were newly hired during the reporting period				√
Social	Labor Practices and Decent Work for Humanity	G4-LA1	Percentage of male employees who were newly hired during the reporting period				√
Social	Labor Practices and Decent Work for Humanity	G4-LA1	Average age of newly hired employees in the reporting period				√
Social	Labor Practices and Decent Work for Humanity	G4-LA3	Return of employees to work and their retention rate(the maternity leave)				√
Social	Labor Practices and Decent Work for Humanity	G4-LA3	The total number of employees who returned to work and were still at work twelve months after returning to work (after maternity leave)				√
Social	Labor Practices and Decent Work for Humanity	G4-LA4	The minimum number of weeks of notice given to employees prior to major operational changes				√
Social	Labor Practices and Decent Work for Humanity	G4-LA5	Percentage of total workforce represented in official health and safety committees				√
Social	Labor Practices and Decent Work for Humanity	G4-LA6	Accident frequency rate for total labor force (IR)				√
Social	Labor Practices and Decent Work for Humanity	G4-LA6	Occupational disease rate for total labor force (ODR)				√
Social	Labor Practices and Decent Work for Humanity	G4-LA6	Lost day rate for total labor force (LDR)				√
Social	Labor Practices and Decent Work for Humanity	G4-LA6	Absence rate for total labor force (AR)				√
Social	Labor Practices and Decent Work for Humanity	G4-LA6	Number of work-related death cases for the total labor force				√
Social	Labor Practices and Decent Work for Humanity	G4-LA7	Work accident rate				√
Social	Labor Practices and Decent Work for Humanity	G4-LA9	Average hours of training of employees of the establishment during the reporting period (by sex)				√
Social	Labor Practices and Decent Work for Humanity	G4-LA9	Average hours of training employees received during the reporting period (by employee category)				√

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Social	Labor Practices and Decent Work for Humanity	G4-LA11	Percentage of total employees who were regularly assessed for performance and career development during the reporting period (by sex)				√
Social	Labor Practices and Decent Work for Humanity	G4-LA11	Percentage of total employees who were regularly assessed for performance and career development during the reporting period (by employee category)				√
Social	Labor Practices and Decent Work for Humanity	G4-LA12	Percentage of employees under 30				√
Social	Labor Practices and Decent Work for Humanity	G4-LA12	Percentage of employees between the ages of 30-50				√
Social	Labor Practices and Decent Work for Humanity	G4-LA12	Percentage of employees over 50				√
Social	Labor Practices and Decent Work for Humanity	G4-LA13	Base salary and salary proportion between men and women according to distinctive operations locations (by employee category)				√
Social	Labor Practices and Decent Work for Humanity	G4-LA14	Percentage of new suppliers surveyed using labor appraisal criteria			√	
Social	Labor Practices and Decent Work for Humanity	G4-LA15	Number of suppliers subject to impact assessments of labor practices			√	
Social	Labor Practices and Decent Work for Humanity	G4-LA15	The number of suppliers identified as having current and potential adverse effects on labor practices			√	
Social	Labor Practices and Decent Work for Humanity	G4-LA15	Percentage of consensus suppliers about improvements in evaluation			√	
Social	Labor Practices and Decent Work for Humanity	G4-LA15	Percentage of suppliers whose relationship with them was finalized as a result of the evaluation			√	
Social	Labor Practices and Decent Work for Humanity	G4-LA16	Number of complaints received during the reporting period		√		
Social	Labor Practices and Decent Work for Humanity	G4-LA16	Number of complaints resolved during the reporting period		√		
Social	Human Rights	G4-HR1	Total number of distinct investment contracts or contracts involving human rights instruments or human rights screening			√	
Social	Human Rights	G4-HR2	Percentage of employees trained in the reporting period on human rights policies or procedures related to human rights aspects of activities				√
Social	Human Rights	G4-HR3	Total number of discrimination cases during the reporting period			√	

MULTIDISCIPLINARY APPROACHES TO SUSTAINABILITY

Müge Leyla Yıldız, Sinan Keskin, Refika Bakoğlu

Social	Human Rights	G4-HR7	Percentage of security personnel regularly trained in the establishment of human rights policies or special procedures and their implementation of security				√
Social	Human Rights	G4-HR9	Percentage of activities subject to human rights reviews or human rights impact assessments		√		
Social	Human Rights	G4-HR10	Percent of new suppliers surveyed using human rights criteria			√	
Social	Human Rights	G4-HR11	Number of suppliers subject to human rights impact assessments			√	
Social	Human Rights	G4-HR11	Percent of suppliers who have been identified as having human rights impacts and who are agreed on improvements themselves as a result of the evaluation			√	
Social	Society	G4-SO3	Percentage of activities assessed for corruption risks			√	
Social	Society	G4-SO5	Total number of confirmed corruption cases			√	
Social	Society	G4-SO5	The total number of cases in which employees are excluded from work due to corruption or confirmed to have been subjected to disciplinary action			√	
Social	Society	G4-SO5	The total number of cases in which contracts with business partners are confirmed to be terminated or not renewed due to violations of corruption	√			
Social	Society	G4-SO8	Total monetary value of significant penalties	√			
Social	Society	G4-SO8	Total number of non-monetary sanctions			√	
Social	Society	G4-SO8	Number of incidents brought to the dispute resolution mechanisms		√		
Social	Society	G4-SO9	Percentage of new suppliers surveyed using the criteria for impact on the community		√		
Social	Society	G4-SO10	The number of suppliers subject to assessment of the impact on the community		√		
Social	Society	G4-SO10	The number of suppliers found to have present and possible adverse effects on the population at a significant scale		√		
Social	Society	G4-SO10	Percentage of conscientiously committed suppliers of improvements in the outcome of the assessment, where it was determined that there is an existing and possible adverse impact on the community at a significant scale		√		

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Social	Society	G4-SO11	The total number of complaints filed by the official complaints mechanisms regarding the effects on society during the reporting period		√		
Social	Product Liability	G4-PR1	Percentage of distinct product and service categories assessed for health and safety impacts		√		
Social	Product Liability	G4-PR2	Total number of complaints related to the health and safety effects of products and services and the voluntary rule-making incompatibility cases within the reporting period		√		
Social	Product Liability	G4-PR4	Total number of non-compliance cases and voluntary codes related to product and service information and labelling		√		
Social	Product Liability	G4-PR5	Customer satisfaction rate		√		
Social	Product Liability	G4-PR8	Total number of leaks, thefts or losses related to customer data		√		
Social	Product Liability	G4-PR9	Total monetary value of significant monetary penalties arising from non-compliance with laws and regulations relating to the supply and use of goods and services	√			

Source. GRI G4. Implementation Handbook, 2014, (p. 23-235)

Table 4. Sustainability Performance Scorecard Corporate Profile Dimension

Sustainability Dimension	Indicator (GRI G4 Report Standard)			BSC Dimensions			
	Sub Dimensions	Indicator Code	Indicator Name	Finance	Customer	Processes	Learning
Corporate Profile		G4-9	Total number of employees			√	
		G4-9	Total number of transactions			√	
		G4-9	Amount of products or services provided			√	
		G4-11	Percentage of employees covered by collective bargaining agreements by total number of employees				√

Source. GRI G4. Implementation Handbook, 2014, (p. 23-235)

3. Findings and Evaluations

According to the Sustainability Performance Scorecard Model, the following table and figures have been obtained. Table 5 is the model results of sustainability and BSC dimensions. It expresses the numerical intersection of 110 sustainability indicators with sustainability and BSC dimensions. Sustainability indicators; 15 economic, 37 environmental, 54 social and 4 institutional profile indicators. This distinction was made according to the GRI G4 reporting standard. BSC has 17 finance, 18 customers, 47 processes and 28 development indicators. All of these indicators are sustainability indicators. Indicators are key indicators from the GRI G4 reporting standard. So the model is also a basic model. Organizations can create sustainability performances. Organizations can also add industry specific indicators while building sustainability performance.

Table 5. Intersection of Sustainability and BSC Dimensions (Number)

Dimensions	Finance	Customers	Processes	Learning and Development	Total
Economic	11	0	0	4	15
Environmental	3	4	30	0	37
Social	3	14	14	23	54
Corporate Profile	0	0	3	1	4
Total	17	18	47	28	110

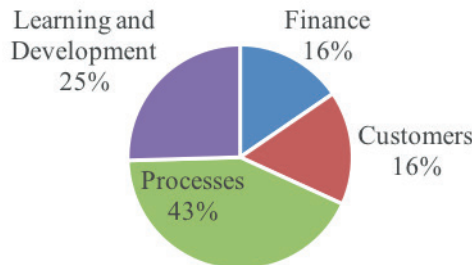


Figure 1. Distribution of Sustainability Indicators in BSC Dimensions, %

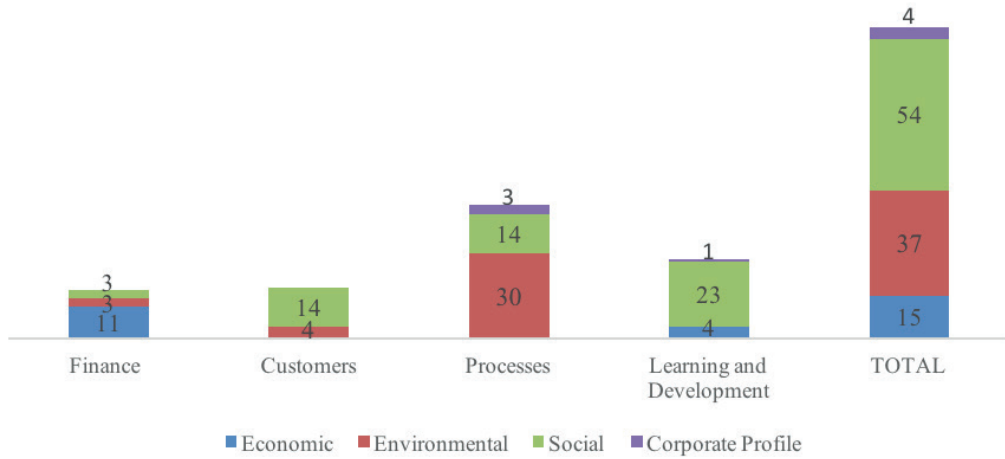


Figure 2. Sustainability / BSC Indicator Dimensions, Number

According to the figure 1, operational processes are at the forefront in sustainability performance. Companies that have been successful in operational processes and process improvement activities will be at the forefront of sustainability activities. In addition, processes are shown to be widespread in the environmental dimension of sustainability in figure 2. According to figure 1, the learning and development dimension comes after the process dimension. According to figure 2, in the learning dimension, it is seen that the social dimension of sustainability in general is the foreground. In this case, the social dimensions of the companies that increase the Corporate Social Responsibility Projects will come to the forefront. Learning dimensions will play an important role in their sustainability. According to figure 1, finance and customer dimensions are equally important. It comes after learning dimension. According to figure 2, the economic dimension of the sustainability of the financial dimension is at the forefront. The social dimension is the forefront, also on the customer dimension.

3. Conclusion and Discussion

Sustainability is to maintain a good position in the current situation and to ensure continuity. In addition to economic factors sustainability, environmental and social factors are also important. Performance criteria must be taken into consideration to ensure sustainability. In this study “Sustainability Performance Scorecard Model” was created. Sustainability indicator sets were established according to our model. For further researches, it can also be generated additional indicators in sustainability measures. The dimensions to be given priority can be determined with respect to strategy, mission and vision.

In this study, intuitive method was used for model setup. The model was established comprehensive. In similar studies in the literature, it is seen that the intersections are made with the intuitive method. In fact, models could be established by methods such as expert opinions or surveys. Different methods (expert opinions, focus interviews, surveys, etc.) could be used instead of the intuitive method of separating the indicators. All of the indicators used in the model are GRI indicators. Since these indications are clear, the intuitive method can be used while partitioning.

The model can be applied in every sector. It can also be used to measure the sustainability of a city or measure the performance of a bank. For example, while the finance-economy dimension is at the forefront in the banking sector, the learning / development-social dimension will come to the forefront in profit-oriented institutions.

The dimensions to come forward can be determined by company strategy, mission and vision. The model is suitable for designing revised models for sector. The model is clear for development and can be viewed from different perspectives.

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2

SUSTAINABILITY PERFORMANCE ANALYSIS OF EAST BLACK SEA PROJECT (DOKAP) CITIES BY USING TOPSIS METHOD

Ahmet Sefa Bir, Özgür Çakır

Abstract

This study was designed to examine the sustainability performances of East Black Sea Project (DOKAP) cities and to compare the sustainability performances of these cities in terms of economics, environmental, and social dimensions. In this study, nine cities within the scope of East Black Sea Project -Artvin, Giresun, Gümüşhane, Ordu, Rize, Samsun, Tokat, Trabzon, and Bayburt- are involved. A total of 52 indicators are taken into account in three dimensions. The TOPSIS method which is one of the best multi-criteria decision making methods is utilized for the analysis. Indicator groups are considered as having equal weights but each indicator has a weight according to number of indicators in indicator group it is involved. Firstly, a holistic approach that includes all indicators is applied. Secondly, a dimensional approach is followed. Finally, rankings both in holistic and in dimensional approaches are presented and discussed. As a result of the study, Rize has the best performance according to holistic approach while Samsun in the social dimension, Rize in the economic dimension, and Tokat in the environmental dimension has the best performances. Moreover, it is seen that economic indicators have a high impact on the results.

Keywords: Sustainability, Urban Sustainability, Multiple Criteria Decision Making Methods, TOPSIS, DOKAP

1. Introduction

Sustainability, which originally implies development and economic activities, is out of purely the economic sense anymore. Various usages of the concept of sustainability such as sustainable environment, sustainable cities, sustainable transportation, sustainable consumption, and sustainable architecture etc. nowadays started to show up. Measuring the sustainability has also gained importance as an agenda item at international organizations' meetings. Approaches

that state the importance of measuring sustainability have emerged as well as the definition of it. Sustainability is measured in terms of social, economic and environmental dimensions and indicators of these dimensions are generally common. It is extremely important to measure the development recorded in sustainability issues with adequate economic, social and environmental indicators by using appropriate methods and to draw road maps according to the results. The concept of urban sustainability is becoming increasingly important in determining the extent to which countries' development goals are achieved.

This study was designed to examine the sustainability performances of East Black Sea Project (DOKAP) cities and to compare the sustainability performances of these cities in terms of economic, environmental and social dimensions. Nine cities within the scope of East Black Sea Project -Artvin, Giresun, Gümüşhane, Ordu, Rize, Samsun, Tokat, Trabzon and Bayburt- are involved in the study. Holistic and dimensional approaches are followed and rankings in both approaches are presented and discussed.

Although the concept of sustainability is not a new concept, it cannot be expressed clearly. There are huge differences in understanding and implementation of the concept. According to the economic theory, sustainability can be explained by the maximization of wealth level (Eş, 2008, p.21). Most of the economists have discounted the base to maximize the benefit from this consumption (Harris, 2000, p.7). In a wide frame, sustainability means that the community, the ecosystem, or any ongoing system is functioning till uncertain future without consuming the main resources (Gilman, 1992).

The concept of "sustainable development" has emerged at international platforms, with the work on sustainability and the issue of solving environmental problems became a priority. Sustainable development was identified by the 1987 Brundtland Report; "meeting today's requirements on condition that future generations will not be deprived of their ability to meet their needs". Unlike other conferences, the Rio Conference in 1992 emphasized the necessity of a multi-lingual and participatory understanding with local governments, non-governmental organizations as well as central government institutions. At the United Nations Conference on Human Settlements (Habitat II) held in Istanbul in 1996, talks were held on the development of sustainable human settlements in a world where adequate housing and urbanization existed for all. After these conferences, the concept of urban sustainability has emerged as a new agenda. According to the 2nd Urbanization Thematic Group Report, the concept of sustainability was associated with the city in the Sustainable Urban Conference held in Rio in 2000.

Urban sustainability or the sustainable city has begun to be put into words for referring to a unit that takes specific balances at the economic, social and environmental dimensions, and is compatible with the regional and global sustainable development goal and contributes effectively to this goal (Sahin, 2010). Sustainable development; economic, social and environmental dimensions, it is difficult to perceive and evaluate it due to its dynamic structure. For this

reason, sustainable development needs to be measured taking into account the economic, social and environmental dimensions. While developing indicators for sustainable development goals, issues such as socioeconomic development, sustainable consumption and production, social inclusion, demographic changes, public health, climate change and energy, sustainable transport, natural resources, global partnerships and good governance are issues to be considered (Arı, 2015: 14-15).

When literature studies on urban sustainability are examined, it is possible to come across many studies made in different disciplines. The development of the concept of sustainability and the importance of environmental policies throughout the world in the last twenty years, is the primary reason why the concept is subject to many studies. With these studies, it has been tried to determine key concepts related to urban sustainability, its applicability in practical life has been tested, how successful applications can be modelled for other cities, and what indicators should be used on city basis.

All the cases in Turkey have been analysed with TOPSIS (Ideal Multidimensional Weighting Method) which is one of the “Multi-Criteria Decision Making” methods in terms of economic, social and environmental aspects of sustainability (Gazibey et al., 2014). As a point of improvement for the TOPSIS method, the ideal solution is the closest alternative and the negative ideal solution is the alternative to be selected at the farthest distance. The ideal positive solution is the solution with the highest utility cost, the lowest cost solution, while the negative ideal solution is the solution point where the benefit is the lowest and the cost is the highest. The most preferred alternatives at the basis of the TOPSIS method lies in the thought that not only the positive ideal solution is the closest but also the negative ideal solution is the farthest alternative. Various indices and indicators used for measuring sustainability were compared and indicators of sustainability to be used in the implementation section were established. In the study, 52 sustainability indicators for sub-dimensions of social, economic and environmental dimensions were used in order to assess the sustainability of 81 provinces.

2. Methodology

In this study, indicators that constitute urban sustainability are examined and a comparison of the sustainability performances of DOKAP cities are presented both in holistic and in dimensional scale. Indicators were determined according to a widespread literature searching. Studies that conducted previously in the world and in Turkey are taken into account and adaptable indicators are chosen for the DOKAP cities. The reasons for preferring the TOPSIS method are that it is simpler and more understandable than other methods, it has a good and easy calculation efficiency, and it allows us to measure the relative performance of each alternative from a simple mathematical equation. It was also preferred that the evaluation factors add the same amount of solving (Eş, 2008: 73). TOPSIS method is applied on data and the

sustainability performance scores of cities are calculated. By using these scores, rankings both in holistic and in dimensional approaches are presented and discussed.

Limitations and Data Collection

Some of the data at the city level in our country is not kept, is not accessible or has not been published has caused some of the representatives not to be included in the analysis. Since urban sustainability analysis has not been carried out regularly over the years, the results of the study were not compared with the past years and a performance analysis was not performed on a yearly basis.

In the analysis, 52 sustainability indicators for economic, social and environmental dimensions are used to assess the sustainability of the nine cities that are DOKAP cities. Social dimension is measured with 7 sub-dimensions and 21 indicators, economic dimension with 7 sub-dimensions and 21 indicators and environmental dimension with 4 sub-dimensions and 10 indicators. Decision matrix used in the study covers data from Turkish Statistical Institute, Ministry of Finance, Ministry of Justice, Ministry of National Education, Social Security Institution, and the State Planning Organization. Data were obtained from the internet sites of the specified institutions and from the reports they published using Level-3 (city level).

Table 1. Dimensions and Indicator Groups

SOCIAL DIMENSION	INDICATOR	ECONOMIC DIMENSION	INDICATOR	ENVIROMENTAL DIMENSION	INDICATOR
JUSTICE / SECURITY	3	INFRASTRUCTURE INVESTMENTS	1	WATER NETWORK	2
EDUCATION	4	ENERGY	1	WASTE SERVICES	3
DEMOGRAPHY	5	LABOR / EMPLOYMENT	3	AIR POLLUTION	1
CULTURE	3	VENTURE	3	AREA SIZE	4
HEALH	2	TOURISM	4		
TRAFFIC	1	TRANSPORTATION	4		
SHELTER	3	FINANCIAL INDICATORS	5		

Indicators are used in proportion to the population at the most basic level so that they can be more meaningful on some occasions. The values of cities have been reassessed by adapting the median because the working orientation of the indicators such as population growth rate and average household size cannot be determined as positive or negative direction.

3. Findings and Evaluations

When the relative distance values of cities are examined in terms of sustainability dimensions, it is seen that the relative distance values (0.9981, 0.7882 and 0.5543) of the first three cities (Rize, Trabzon and Samsun) are higher.

Table 2. Sustainability Performances

NO	CITIES	C VALUE
1	Rize	0.9981
2	Trabzon	0.7883
3	Samsun	0.5543
4	Ordu	0.2867
5	Giresun	0.2049
6	Tokat	0.1075
7	Bayburt	0.0843
8	Artvin	0.0281
9	Gümüşhane	0.0004

In the social dimension, Samsun and Trabzon were at the forefront of other cities. On the economic dimension, Rize is very far ahead of all cities. Tokat is in the first place in the environmental dimension.

Table 3. Sustainability Performances in Terms of Dimensions

Social Dimension		Economic Dimension		Environmental Dimension	
City	C*	City	C*	City	C*
Samsun	0.9983	Rize	0.9985	Tokat	0.9203
Trabzon	0.9845	Trabzon	0.7883	Trabzon	0.9037
Bayburt	0.7335	Samsun	0.5543	Bayburt	0.8930
Tokat	0.6259	Ordu	0.2867	Artvin	0.8806
Rize	0.4710	Giresun	0.2049	Rize	0.8788
Artvin	0.3283	Tokat	0.1075	Gümüşhane	0.8377
Ordu	0.2228	Bayburt	0.0843	Giresun	0.7873
Gümüşhane	0.1759	Artvin	0.0281	Ordu	0.1182
Giresun	0.0010	Gümüşhane	0.0001	Samsun	0.0063

When the results are examined, it can be said that the economic performance is very effective in the order of the cities. The social, economic and environmental dimensions in the study are equally weighted. Likewise the sub-dimensions are equally weighted. For this reason, they are equally effective in analysing sustainability.

In a study by Gazibey et al. (2014) and in the overall order of sustainability in this study, no city was found to dominate in all dimensions in general. This proves the correctness of urban sustainability studies in all dimensions, as well as for each dimension separately.

In some studies, indicator weights were determined by AHP or factor analysis. However, due to the inhomogeneous structures of the cities, it is considered more useful to determine the indicator weights according to the expert opinions for each city. In view of the dynamics that provinces have within themselves, it is thought that the studies of sustainability analysis should be done singularly or with geographical limitations. It is thought that efforts to increase the number of indicators for the environmental dimension in the name of sustainability studies on cities will be conceptually more productive.

4. Conclusion

When the order in which the DOKAP cities were analysed as a whole was examined, it was determined that the order of the cities did not parallel with the results of the similar studies. One of the most important reasons for this is that the work has not been done on the indicators that represent the same year. In addition, while evaluating the results of urban sustainability analysis efforts, it is necessary to demonstrate the necessity to take into account the dynamics, regional differences and inhomogeneous structures of cities themselves.

When the rank order of sustainability performances of DOKAP cities is examined, it is determined that there is no dominance in three dimensions. In other words, it appears that there is no balanced distribution in three dimensions. Leading provinces are Rize, Trabzon and Samsun at holistic analysis but Samsun in social dimension, Rize in economic dimension, Tokat in environmental dimension has the highest performances. Although Rize has highest score at overall evaluation, it is in fifth place both in social and in environmental dimension. This result shows how well the sustainability analysis is done in each of the three dimensions rather than depending on all the indicators. From the point of view of dimensional analysis results, it can be said that the performance at the economic level is effective in the order of the illusions since the results of the sustainability analysis made on the economic dimension are very similar to the results of holistic analysis.

When the studies of urban sustainability are examined, it is seen that the weighting is done in different forms. It is thought that it would be appropriate to equate weightings with the studies on cities located in the same region. Sub-dimensions and indicators used in the study need to be improved. In this way, cities' sustainability performances will be evaluated on a wider frame. It is considered that urban sustainability studies should be carried out regularly by the related institutions of the city and the follow up of their results will be an important application in terms of urban development.

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**SUSTAINABILITY PERFORMANCE ANALYSIS OF EAST BLACK SEA PROJECT (DOKAP) CITIES
BY USING TOPSIS METHOD**

Ahmet Sefa Bir, Özgür Çaktır

- Lu I.J. Lin S.J. Lewis C. (2008) “Greyrelation Analysis of Motor Vehicular Energy Consumption in Taiwan”, *Energy Policy*, 36 (7): 2556-2561.
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Part 3

ENVIRONMENTAL
SUSTAINABILITY

1

IDENTIFICATION AND EVALUATION OF APPLICABLE TECHNOLOGIES' ENERGY SCENARIOS OF A BIG SCALE BUILDING

Hatice Sözer, Ergin Kükrer, Utku Simitli

Abstract

The improvement of the building energy performance could be achieved by better physical conditions and efficient building system integration. However, configuration of diverse building systems' working scheme during whole year is very critical to maximize energy efficiency of the building as this research paper aims to prove. This research addresses the effect of different technologies configuration and their control scenarios during the integration process in a big scale building based on their energy performance. The research is followed through a case study. In total, eight energy scenarios concerning the varied application of lighting, domestic hot water (DHW), ground source heat pumps and, thermal system are identified and evaluated. Out of these eight different scenarios, best scenarios are evaluated in detail. Results revealed that within the integration of presented scenarios, more than 10% energy saving in annual energy consumption can be obtained which leads 141,638 kg CO₂ emission reduction.

Keywords: *Building Integrated Renewable Technology, Energy Efficiency, Optimization of the Building Systems.*

1. Introduction

Energy costs and carbon dioxide emissions are getting increased day by day, not only replacing the conventional systems with sustainable ones but also optimizing the energy use and the operation of them is need. Recently, various studies indicate that, residential buildings are responsible for substantial amount of the total energy consumption in developed countries [Al-louhi et all, 2015]. In this context, energy management in the building sector is referred as a milestone. As this paper aims to discuss, the integration of control scenarios in a big scale building can have great impact on the energy performance considering both economic and environmental aspect.

Control scenarios are directly related to Information and Communication Technologies (ICT) which represents a remarkable alternative to provide capabilities of intelligence, autonomy and support in making decisions for energy management systems [Kramers et al, 2014]. Recently, ICT-based solutions are considered to be one of the promising solutions in the field of building energy performance improvement [Moran et al, 2016]. While ICT offers better understanding of how building operates, it enables users to take an action and improve the effectiveness accordingly. In the literature, there are several researches, which have been carried out to emphasize the significance of the topic.

2. Methodology

This research work was done based on an existing building. The methodology of the research work was composed of two steps; 1st step: Identification of energy scenarios and 2nd step: Evaluation of energy scenarios.

First Step: Identification of Energy Scenarios

As well as assigning the right system, identifying each system different configurations in order to keep them working efficiently is important. Consequently, a set of energy scenarios about lighting, DHW and thermal system is identified and evaluated in this work.

Identification of existing building specifications

The selected pilot building is located in Istanbul. It was built as an elderly house and has 8 stories. The total conditioned floor area of the building is 18.108 m². The pilot building has 2 basements and 6 above grade floors. Basement floors mainly consist of common spaces such as shelter, indoor pool, mechanical room, theatre, laundry rooms, whereas above-level floor include resident rooms mainly. In total 228 resident rooms take place in the building. In the top floor, along with the residential rooms common zones such as meeting and restaurant rooms exist. With the common spaces, area of the building is 21983 m². Floor plans for the building and internal distribution of the spaces were given on Figure 1, additionally building systems on Table 1.

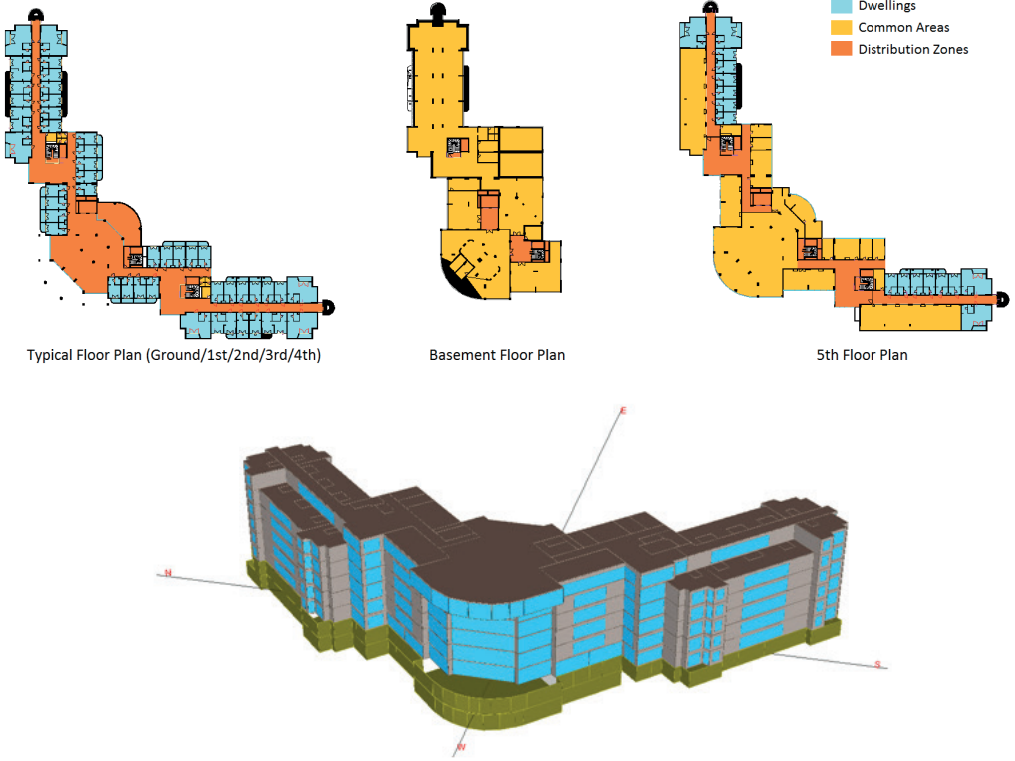


Figure 1. Floor Plans and simulation model of the building.

Table 1. Mechanical systems of existing and baseline case.

	Existing Case	Baseline Case	Control Strategies
Cooling	Air Cooled Chiller	Air/Water source heat pump	<ul style="list-style-type: none"> Predictive Zone Set Point Control Heat Pump Sequence Control
Heating	Natural gas boiler	Air/Water source heat pump	
DHW	Natural gas boiler	Solar thermal system Water source heat pump	<ul style="list-style-type: none"> Loop Set-point Temperature Variation Control DHW Demand Control Solar Collector and Heat Pump Sequence
Lighting	LED	LED	<ul style="list-style-type: none"> Automatic dimming control Automatic switching control Occupancy scheduled control

When building energy model was created, energy analysis of the model was performed for both existing and baseline cases first. Results of both existing case and baseline case were given on Figure 2. In the following sections, baseline model was used for evaluating scenarios. As seen on given tables, natural gas consumption of the whole building was 4,612,285 kWh per year. However, with new system, heating completely covered by integrated renewable systems. Integration of heat pump system has reduced total annual energy consumption by %9,7. On the other hand, electrical consumption, especially the pump consumption, has increased 58%. Validation of simulation results for existing case has been fulfilled by comparing the results with the natural gas and electricity bills.

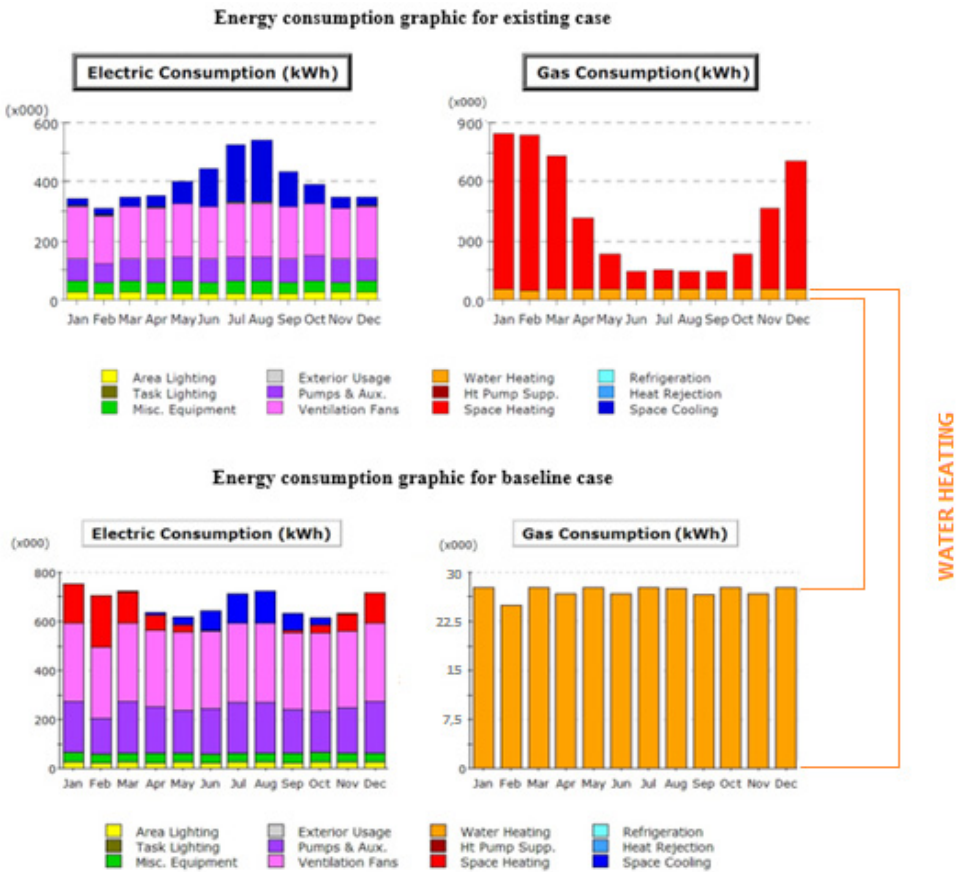


Figure 2. Energy consumption graphs for existing and baseline case.

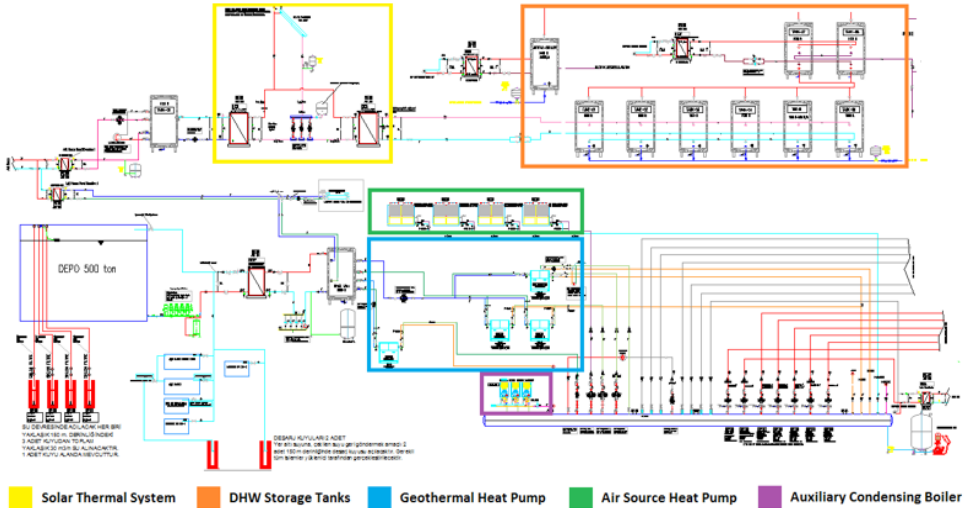
Identification of the building's mechanical and electrical systems

According to analysis of building's energy consumption results, mechanical and electrical systems of the building are determined. Instead of ineffective natural gas boilers, renewable

technologies are introduced to building as an intervention. These technologies are; 450kW solar thermal system, 740 kW geothermal heat pump, 520 kW air source heat pump and 300 kW auxiliary condensing boiler for heating and cooling systems. Mechanical scheme of mechanical systems were represented on Figure 3.

In addition to mechanical system there are various electric appliances as well. Miscellaneous equipment, namely indoor electric equipment such as fridges, white goods or any electrical device which creates plug load have 449,102 kWh annual consumption regarding the simulation. Apart from plug loads, lighting system also contains a high portion of energy consumption in the building with 333,668 kWh annually.

Based on the demand, solar thermal system was modelled in energy simulation software. It was found that solar thermal systems couldn't meet 100% of DHW demand. (Figure 4) In these seasons, the system was supported by heat recovery geothermal heat pump, which has 200 kW capacity of heating/cooling. The heat pump was fed by geothermal water drew from borehole and had a constant temperature of 13°C.



Mechanical Systems				
System	Solar Thermal	Geothermal Heat Pump	Air Source Heat Pump	Auxiliary Condensing Boiler
Capacity (kW)	450 kW	740 kW	520 kW	300 kW

Figure 3. Mechanical System Scheme.

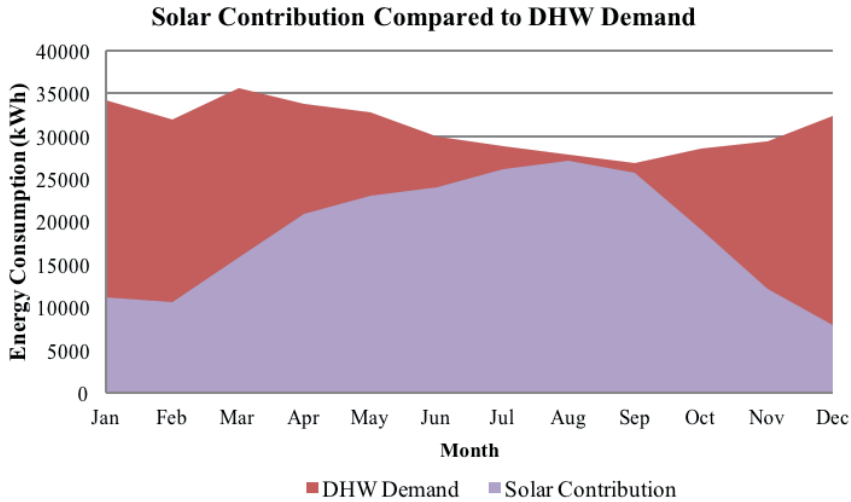


Figure 4. Solar Contribution compared to DHW demand.

As far as thermal system is concerned, combination of air source and geothermal heat pump was installed.

Identification of important parameters

Before evaluating energy scenarios, a set of significant parameters was identified to operate the systems in an efficient way. Careful engineering and implementation of energy management and control in a big scale building is a need to achieve energy efficient operation. The following principles should be considered to operate building service plants in an energy-efficient manner:

- Temperature level, Network Losses, Occupancy, Usage of areas, Operating modes and Set-Points, Comfort range, Demand

It is not always enough to use the best available components to achieve a high level of energy efficiency. The components must be matched not only technically but also in the way they are controlled.

Identification of control scenarios

A set of applicable control scenarios were identified for each system in this research. In total, eight control scenarios were evaluated to acquire the most comprehensive control scenario. This scenarios were defined for three different systems; lighting, domestic hot water and thermal systems.

- Lighting Scenarios

Since the building is a big scale building and there are many multifunctional common rooms as it was previously defined in Figure 1, lighting consumption for common spaces.

Control Scenario 1: Automatic Dimming Control

In the field of lighting appliances, daylight responsive dimming systems have a remarkable potential to reduce lighting consumption depending on the daylight times of a given zone and structural-wise specifications of the building and application [Park et al, 2007]. Three different dimming strategies were created according to different minimum light fraction and power input. Minimum light fraction and power input of these strategies were shown on Table 2.

Table 2. Specifications of automatic dimming scenarios.

	5% dimming	10% dimming	22% dimming
Min. Light Fraction (%)		10	22
Min. Power Input (%)	20	19	36

Control Scenario 2: Automatic Switching Control

Differently, automatic dimming system increases or decreases power input and light output in equal discrete level based on the illuminance level in switching control scenario. In this study, two different switching strategies were created based on step number. Lighting control strategies for 2 level and 3 level were introduced in Table 3.

Table 3. Specification of automatic switching control

	2 level+off		3 level+off	
	Input Power (%)	Output Illuminance (%)	Input Power (%)	Output Illuminance (%)
Step 1	100	100	100	100
Step 2	50	50	67	67
Step 3	-	-	33	33
Off	0	0	0	0

Control Scenario 3: Time Switching Control

Another aspect in energy consumption of lighting system is related to operation schedule. If the schedule is regulated accordingly, the lighting system operation of the space can be scheduled automatically and energy efficiency can be obtained. These schedules can be fixed or vary by days [Wang, 2011]. This strategy was applied to especially common rooms, which are used a certain time period in a day such as restaurants or theatres. For this study, lighting operation schedule rearranged according to the occupancy profile. Comparison of restaurant, meeting and hobby rooms baseline lighting control schedule and occupancy scheduled control schedule can be seen on Figure 5.

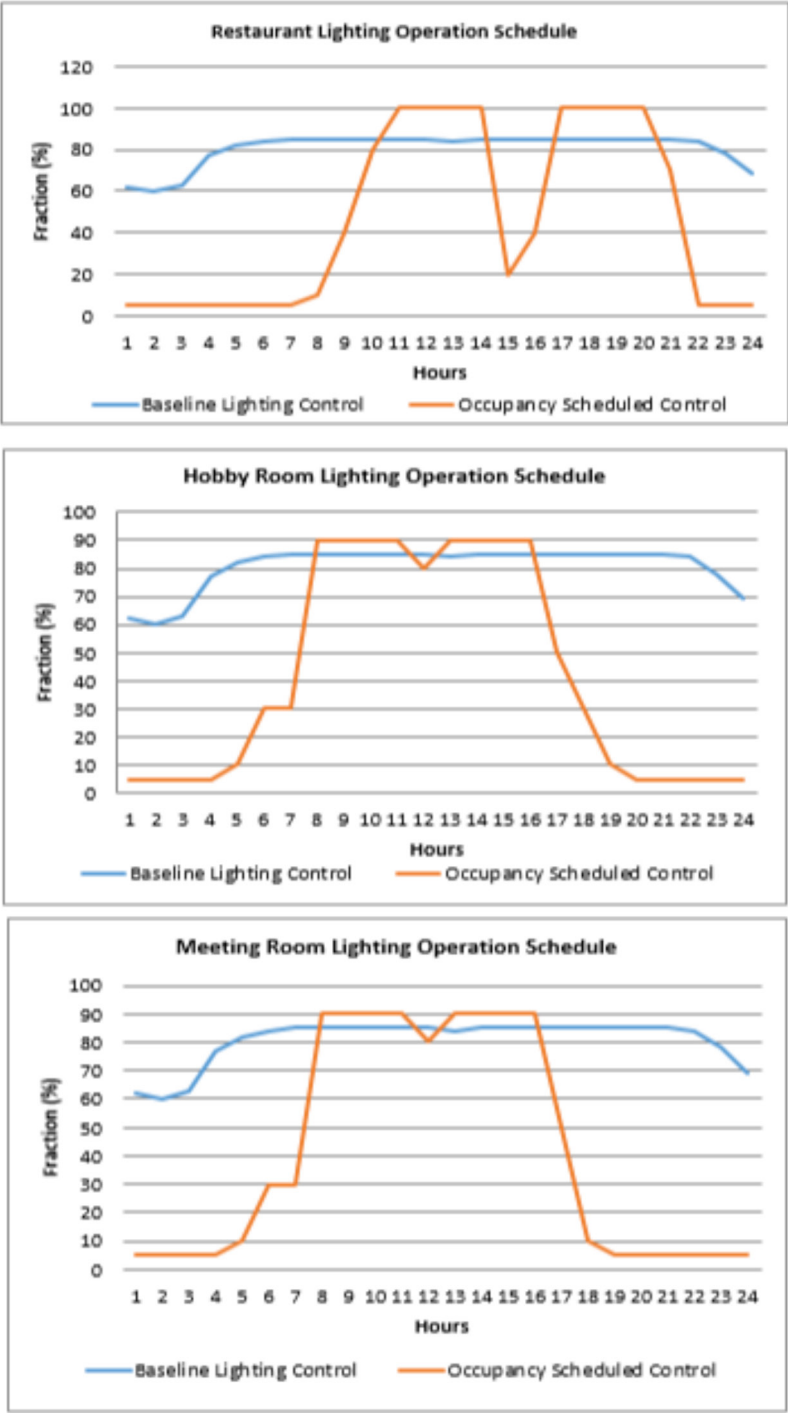


Figure 5. Lighting system's operation schedule for restaurant, hobby and meeting rooms.

DHW Control Scenarios

DHW consumption covers a large portion of consumption in residential places. According to statistics, energy used for hot water preparation can cover more than 30% of total energy consumption [Burzynski, et al, 2000]. Yet, obviously, hot water consumption ranges depending on the typology and occupant behavior of the building. In this context, ASHRAE Handbook defines average DHW consumptions for different types of buildings. For health care facilities, average consumption of DHW is given “69,7” l/day/bed in table “Hot-Water Demands and Use for Various Types of Buildings” [ASHRAE, 2011]. Taking into consideration that the selected building is an elderly house and has many dwellings, a control strategy adjusting demand and set-point would have a great effect on the total energy consumption. Accordingly, three different scenarios were identified about DHW.

Control Scenario 4: Loop Set-point Temperature Variation Control

As a consequent, loop set point variation control scenario was identified to reduce wasted energy and improve efficiency of the system for the case building. Energy consumption of DHW heater was decreased with regulated set-point schedule according to the occupancy demand profile. For this purpose, two control scenarios determined based on set-point values (55°C and 50°C), when hot water demand is zero or very low.

Control Scenario 5: DHW Demand Control

With demand control strategy, operating times of DHW circulation pump was optimized when hot water was provided based on consumer demand. For this purpose, DHW demand was continuously monitored and circulation pumps turn on only if consumer needs hot water.

In addition to circulation pump control, demand control regulates the hot water generation based on the hot water usage profile. In this way, DHW heater produces only certain amount of hot water according to the specified schedule. Operational difference between baseline operation and demand control scenario represented on Figure 6.

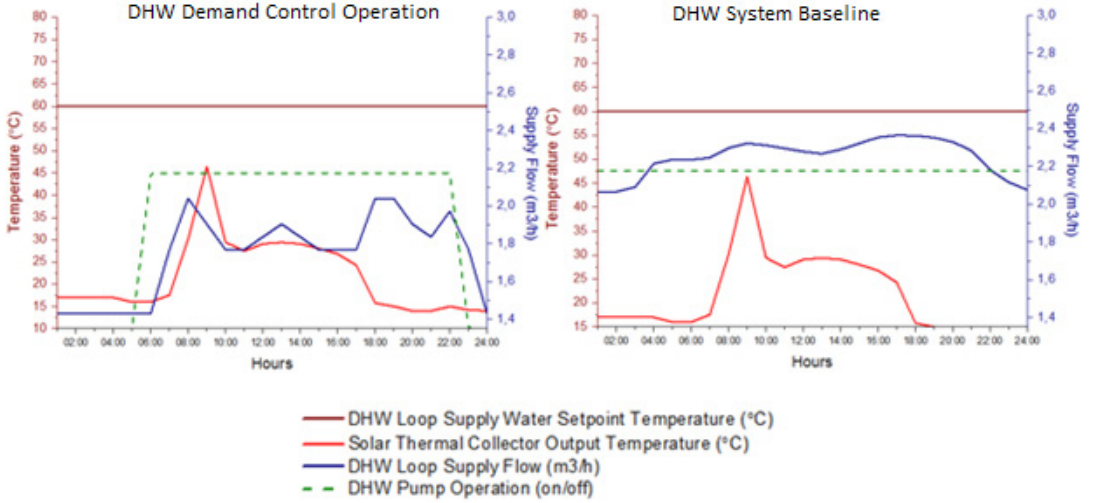


Figure 6. DHW demand control and baseline operation comparison.

Control Scenario 6: Solar Collector and Heat Pump Sequence

In the pilot building, solar thermal and heat pump systems were used together. Combined solar thermal and heat pump systems have a great potential [Emmi et al, 2015]. DHW system operation and performance were analyzed and most efficient working operation period was determined for these two systems.

DHW heater system operates based on solar thermal collector outlet temperature. Heat pump is fed by geothermal water drew from borehole and has a constant temperature of 13°C. To reach the design temperature of 60°C, any solar collector outlet temperature lower than 13°C would be inefficient due to increased temperature difference. Thus, seen from Figure 7, simulation results show that when solar collector loop reaches lower temperature than 13°C, the DHW system that works with solar collector and heat pump sequence scenario was consuming lower energy than the DHW system that works in baseline operation.

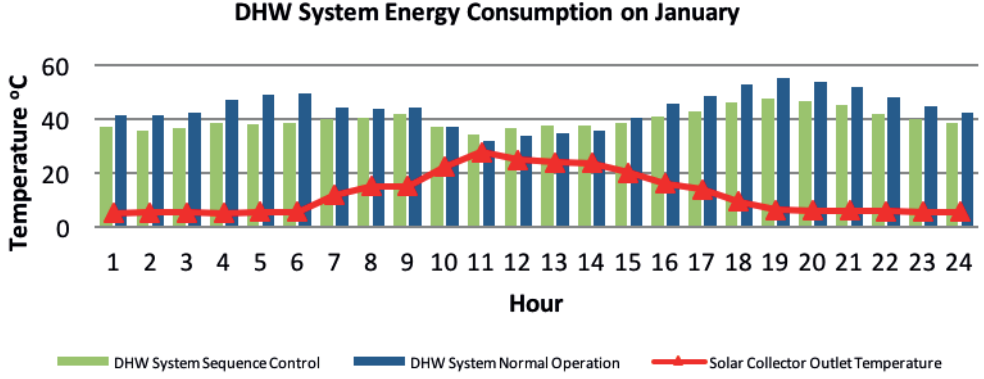


Figure 7. Effect of solar thermal outlet temperature on DHW system energy consumption in January.

Thermal System Control Scenarios

As the building has multiple functioned and individual used areas as well as common spaces, each group of spaces are controlled separately. Consequently, thermal system control scenarios were identified.

Control Scenario 7: Predictive Zone Set Point Control

In the control scenario, a specific day period was selected to see the effects during the day. Historical period of training data set was determined including weather data, zone operative temperatures and energy consumption and the thermal model of the building was learnt on this training data in order to predict the future period's set point that minimizing the cost of energy.

Figure 8 shows the hourly profile of set points and HVAC consumptions for both the normal operation and predictively optimized scenarios. Considering the weather forecast data, zone temperature was optimized for the next couple of hours in order to minimize the energy consumption. In some periods the HVAC consumption was higher than the consumption of normal operation due to the fact that the predictive control action was allowing to the control system to pre-heat or pre-cool the zone in order to capture the next couple of hour's thermal behavior.

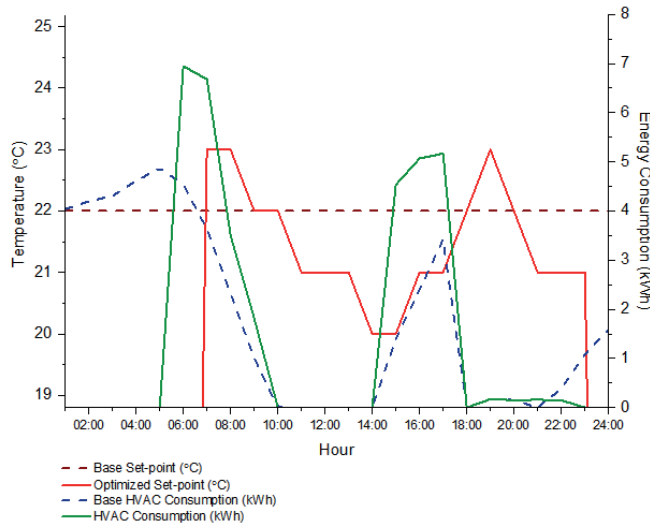


Figure 8: Energy consumption and set-point comparison of control scenario 7.

In optimization, thermal comfort of inhabitants is another issue to be considered. Consequently, ambient temperature must comply with thermal standards, such as TS EN ISO 7730 [Turkish Standards, 2002], which is a standard related to ergonomics of the thermal environment. Therefore, operative temperature value range was defined between 20 and 24 °C to provide thermal satisfaction. In occupied hours set point temperature was ensured to stay between these values as indicated on Figure 9. By this way, not only energy efficiency, but also thermal comfort was obtained.

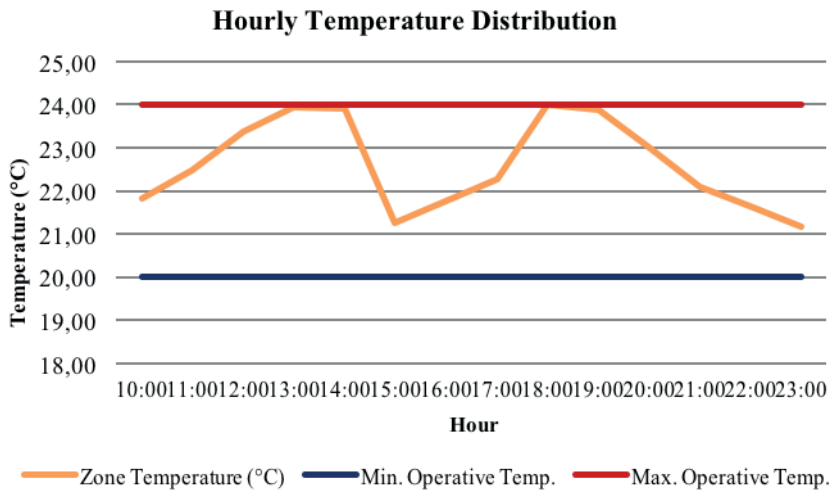


Figure 9. Hourly temperature distribution of a common zone.

Control Scenario 8: Heat Pump Sequence Control

As previously indicated, heating and cooling of the building is going to be covered with a set of heat pumps. These heat pumps were designed to be composed of geothermal and air source heat pumps. According to Nam et al.'s studies, a well-controlled hybrid system is highly efficient and performance increases by 2-7% compared to water cooling systems and 4-18% compared to air cooling systems [Nam, et al. 2010]. Yet, sequence control amongst different systems is a requirement to obtain the maximum efficiency. Accordingly, control scenario 8 is evaluated and operational sequence is further investigated.

Second Step: Evaluation of Energy Scenarios for each technology

As explained in previous sections, each scenario has different configurations.

Generation of the baseline model: All factors that affect heating/cooling loads were modelled in detail to get precise results for energy consumption.

Evaluation of scenarios

After baseline model was generated, above-mentioned scenarios were integrated to the energy model. Results were taken for each individual scenario as it covered henceforward in this section.

-Lighting Scenarios

In this section, pre-identified three different control scenarios were evaluated for lighting case.

Evaluation of Control Scenario #1 – Automatic Dimming Control

In the first control scenario, automatic dimming strategies were analyzed. As identified in the section 2.1.4.1, three dimming strategies were evaluated taking lighting fractions and power inputs on the basis. 5%, 10% and 22% dimming were considered in different zones. These scenarios were applied to the 5 common areas on the 5th floor and modelled in e-Quest.

For different dimming control strategies, monthly energy consumptions can be examined on Figure 10. Change of final energy density values can be observed on Table 5 according to the building simulation results.

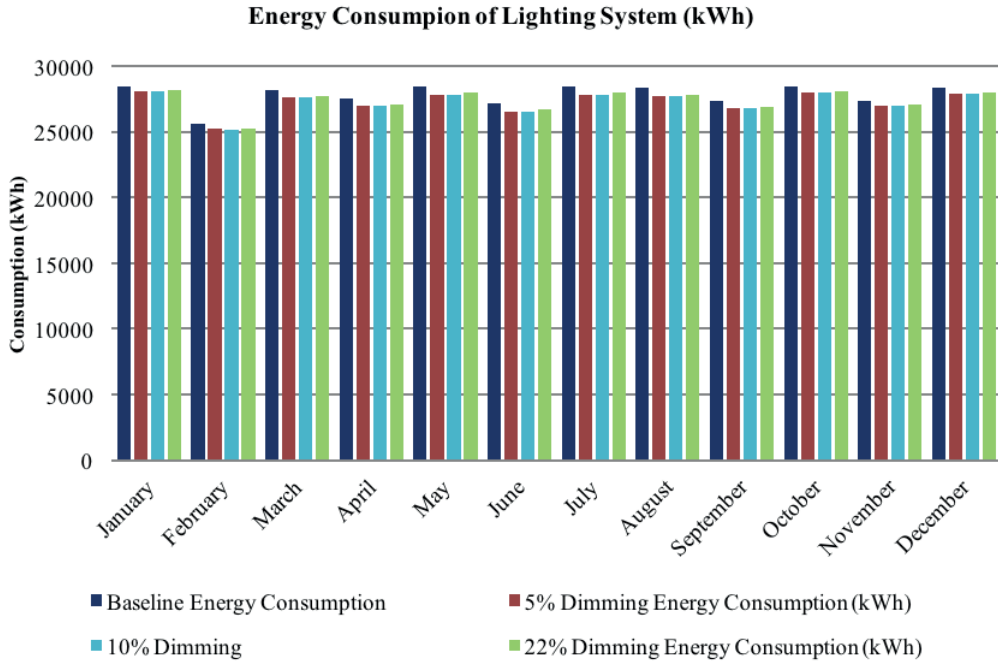


Figure 10: Monthly energy consumption of lighting system for different dimming scenarios.

As seen from Figure 10, monthly energy consumption changes from month to month. It changes due to number of total days in a month as well as considering weekend and weekdays since in weekdays lighting schedule differs from weekend lighting schedules. Lighting schedules were introduced with reference to nursing home standards given in e-Quest. In addition to monthly consumption, energy saving ratio in each dimming scenario also varies from month to month, however, it is mainly between 1,4-2,4%. Since it is known that average daylight illuminance reaches peak values in summer months, most energy savings can be obtained in summer months. Undoubtedly, orientation and window-to-wall ratio of referred space is another key parameter as far as daylighting was addressed.

As total saving ratio is concerned, based on 5% dimming scenario, reduce in annual lighting consumption reaches peak summer months, (June, July) with 2,3%, while for short winter months (November, December and January) saving percentage was 1,4%. Annually 5% dimming scenario leads 1,8% saving in building's total lighting consumption.

10% dimming scenario has also best saving ratios in summer months, 2,4% in June and 2,3% in May and July, as well as having lowest ratio in December with 1,4%. In general, this scenario leads 1,9% reduction which was also presented in Table 5.

Lastly, similar to 5% and 10% dimming scenarios, 22% dimming control scenario has best saving ratios in June and July with 1,9% reduction, as only 1,1% energy saving can be obtained during December. Total annual energy reduction ratio of 22% dimming scenario is 1,5% which makes it the most inefficient scenario. The reason for this is previously defined minimum power input ratios (See. Table2) as 22% dimming scenario has the most minimum power input ratio with 36% amongst others.

Evaluation of Control Scenario #2 - Automatic Switching Control

Similar to first control strategy, automatic switching scenarios are also set for the same common areas placed on the 5th floor. Yet, unlike dimming control scenario, switching control enables to switch between defined steps based on the availability of natural daylight. Input power and output illuminance from step to step as given in Table 5 previously. Taking these values on the basis, two level and three level switching was evaluated. For switching control scenarios hourly energy consumption for each month can be observed on Figure 11. Final energy density was decreased with these control scenarios and it can be examined in detail on Table 5.

Parallel to dimming scenario, switching control strategy pretends to be more effective in summer months as daylight hours increases. In June and July months, monthly lighting consumption energy saving ratio of whole building reaches up to 2,8% for 2 level switching and 2,9% for 3 level switching. In total, taking baseline lighting consumption as a base, scenarios lead 2,2% and 2,6% reduction for 2 level switching and 3 level switching respectively.

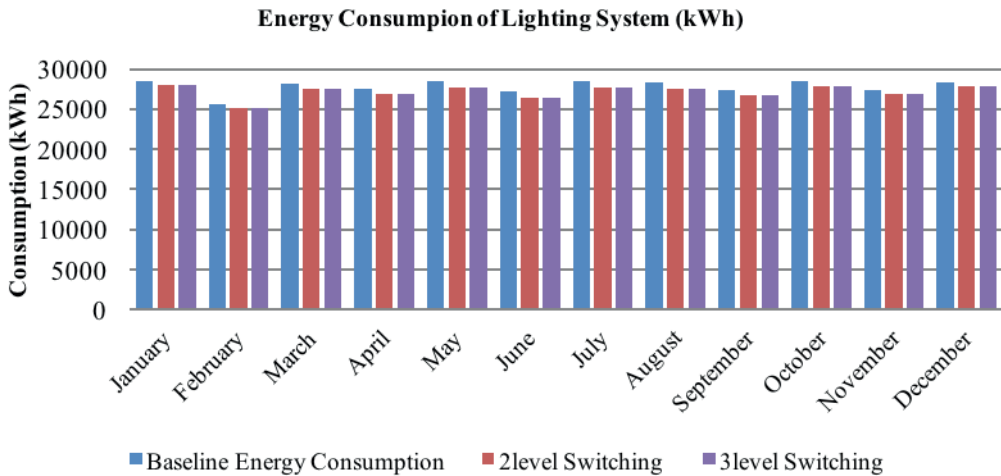


Figure 11: Monthly energy consumption of baseline and switching control strategy.

Evaluation of Control Scenario #3 - Time Switching Control

Lastly, time switching control scenario was evaluated for 5 common areas placed in the fifth floor. Monthly energy consumption of the baseline system and timer switching control scenario can be found in the following Figure 12. In addition to this, change of final energy density and saving ratios were given in the Table 5.

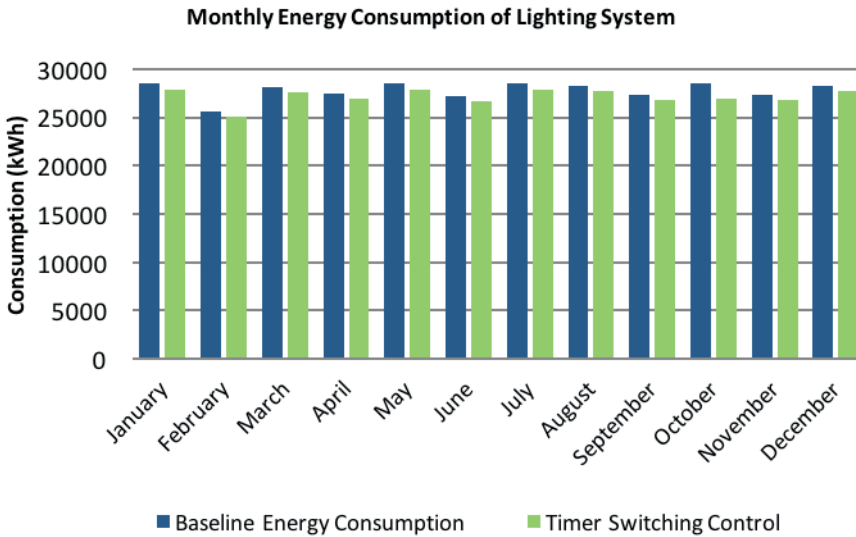


Figure 12: Monthly energy consumption of baseline and timer switching control strategy

According to the results, occupancy scheduled lighting control strategy reduced annual lighting energy consumption by 2,4%. Especially in common areas which are occupied only certain period of time, time switching control can lead to higher efficiencies. Nonetheless, this strategy cannot be generalized for residential areas.

DHW Scenarios

As far as DHW is concerned, three different scenarios were evaluated; Loop set-point temperature variation control, demand control and solar collector – heat pump sequence. In this section, these three scenarios were evaluated in detail.

Evaluation of Control Scenario #4 - Loop Set-point Temperature Variation Control

In the first DHW scenario, loop set-point temperature was examined to see the impact of set-point temperatures. Accordingly two set-point values of 50°C and 55°C are defined. Building

energy analysis in e-Quest was performed to evaluate the effect of temperature variation control strategies on DHW Heater energy consumption. Monthly energy consumption of DHW heater in baseline operation and set-point variation operation represented on Figure 13.

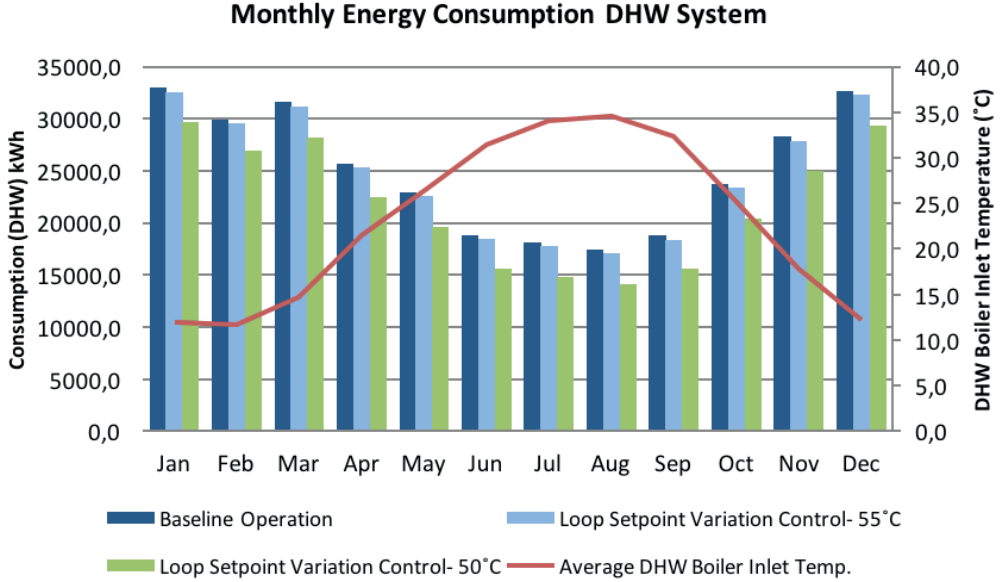


Figure 13: Monthly energy consumption of DHW Loop set-point variation scenario and baseline operation.

According to the results, annual energy saving ratio is 13% for 50°C and 1,6% for 55°C with using set-point regulation based on demand profile. Density of final energy consumption was reduced as it represented on Table 5.

In Figure 13 average monthly DHW boiler inlet temperature was also addressed as well as monthly energy consumption. As results confirm, DHW energy consumption of the building depends directly on the DHW boiler inlet temperature, which varies between 12-35 °C, based on the months. Obviously, summer months have the lowest DHW energy consumption since inlet temperature reaches above 30°Cs. Therefore, loop set-point variation control with 50°C has maximum energy saving in August with 19% energy reduction. Whereas, according to results of 55°C loop set-point variation control.

Evaluation of Control Scenario #5 - DHW Demand Control

Secondly, demand control scenario was evaluated for DHW system. According to demand, circulation pumps and DHW heater running hours have been adjusted in energy model. Demand control strategy has significant effect on DHW circulation pump as well as DHW heater.

According to the building energy simulation results, monthly effect of this control strategy on heater and pump energy consumption can be observed on Figure 14.

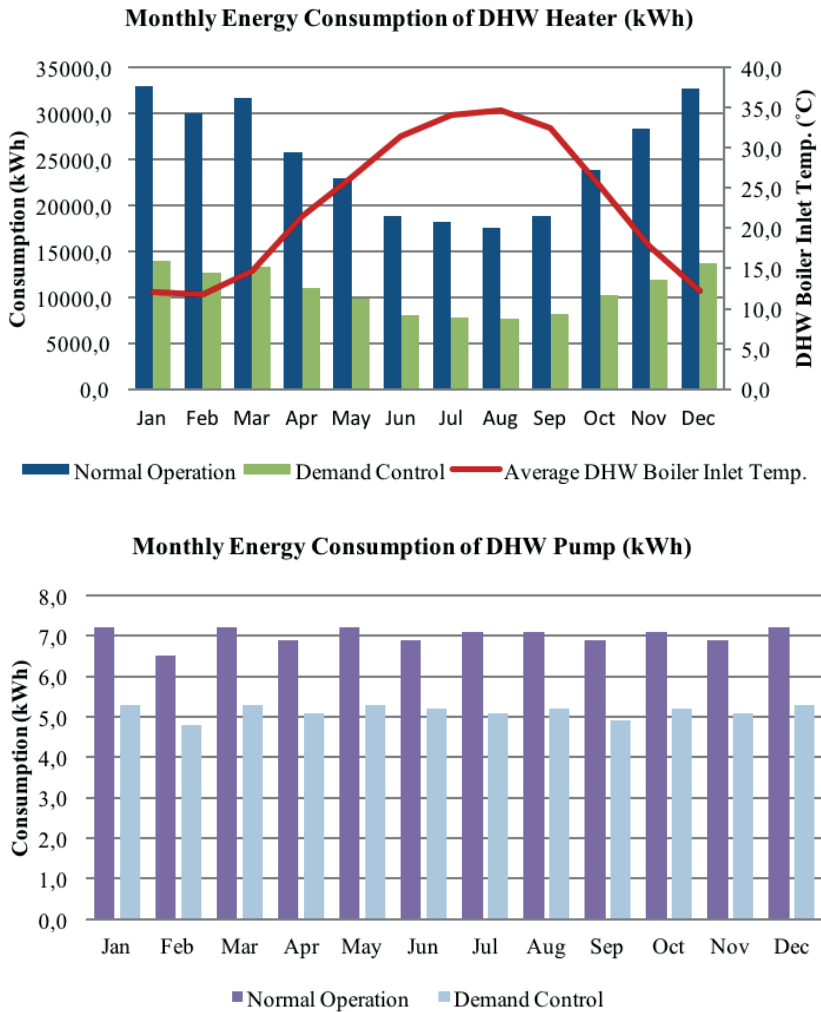


Figure 14. Monthly Energy Consumption of DHW system and pump for baseline operation and demand control operation.

Demand control scenario leads reduction on pump energy consumption by 26,6% and DHW heater energy consumption by 57,4% annually as it can be derived from Figure 14 and Table 5.

Evaluation of Control Scenario #6 - Solar Collector and Heat Pump Sequence

Baseline model of the building was created with the natural gas boilers as previously explained. In this control scenario, defined new system was integrated into e-Quest model. As well as solar collector contribution to DHW demand, interoperability of solar collector and heat pump sequence were investigated. Monthly results of control scenario was given on Figure 15 as it follows.

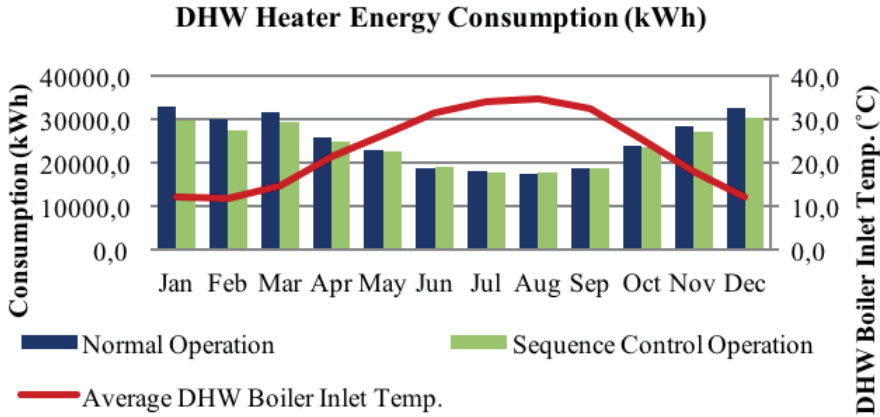


Figure 15: Monthly Energy Consumption of DHW system for baseline operation and sequence control operation.

As seen from Figure 15, solar collector and heat pump sequence control scenario is convenient and effective, apart from summer months, which can be explained by ground-water temperature. When taken into consideration that groundwater temperature has a constant value for a year and solar collector outlet temperature changes month by month (see: Figure 7); lower solar collector loop temperatures creates inefficiency, especially in cold winter months. In these months, if sequence control takes place and supplies DHW needs with only ground-water heat pump instead of combination of these two systems, energy saving can be achieved. Reduction in DHW energy consumption reaches peak in January with 9% and in total 4% annual energy saving can be obtained with this scenario. However, in August instead of saving; combination of heat pump system could lead to inefficiency and increase consumption by 1,2%. As previously given on Figure 4. Solar Contribution compared to DHW demand, in August, covering all DHW needs with only solar collector system would be more efficient compare to combination of solar and heat pump system.

Thermal System Scenarios

Given in Section 2.1.4.3, in the demo building two thermal system scenarios are identified which are predictive zone set point control and heat pump sequence control. The evaluation and results of these two scenarios were investigated in this section.

Evaluation of Control Scenario #7 – Predictive Zone Set Point Control

Predictive zone set point control scenario was applied taking a common zone on the basis since this strategy can only be applied to non-residential places due to indoor environmental quality issues. Accordingly, results were evaluated for a restaurant zone placed in the fifth floor.

In the evaluation phase, new operation schedule for the restaurant zone was generated based on SVM model which was defined previously. In the baseline case even restaurant is unoccupied between 01:00 and 05:00 a.m, heating systems still work to keep the zone in set point temperature of 22°C. When this scenario was applied and operation of heater was set as switched off for mentioned time period; zone temperature ranges between 19 and 18 °Cs in unoccupied hours. Heating schedule starts at 06:00 a.m and zone temperature reaches 22°C by 07:00 a.m. The comparison of annual energy consumption of baseline and predictive set point control strategy was given in Table 5. According to results, energy consumption for heating and cooling was diminished up to 22%. When it was applied to suitable common zones, it was expected to reduce the energy consumption up 20% to 25% in each zone respectively. However, outside temperature, occupancy and schedule of reference zone also taken into consideration in detail.

Evaluation of Control Scenario #8 – Heat Pump Sequence Control

In this strategy, each system was modelled as a primary system to analyze specifications of each system better. The results revealed that geothermal heat pump system consumes less energy (28% in overall consumption) when compared to air source heat pump. Figure 16 indicates the monthly comparison of each system.

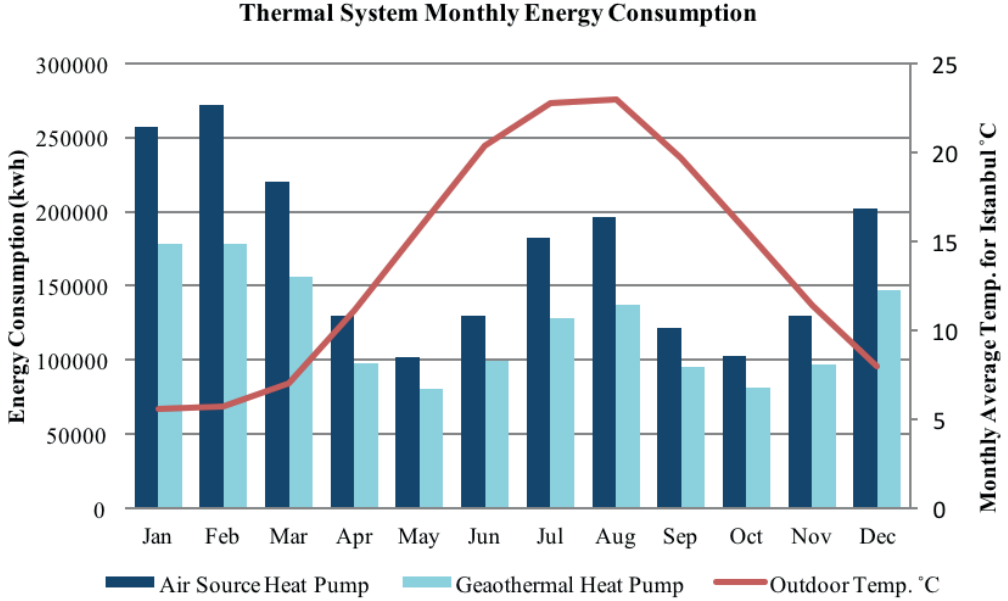


Figure 16. Comparison of monthly energy consumption of ASHP and GHP.

Energy consumption of air source heat pump is directly related to air temperature. Relatively, in winter and summer months which have harsh air conditions consumption of Air Source Heat Pump (ASHP) increases drastically. Whereas, in geothermal heat pump, the main heat source is the water drew from borehole and its temperature remains same almost every month in a year. As a result of this, efficiency of Geothermal Heat Pump (GHP) is always higher than ASHP.

According to the results, primary source which covered the thermal demands would be geothermal heat pump in the building. Air source heat pump was considered backing up heating and cooling in case peak loads. The comparison of final energy density of each individual system was given in Table 4;

Table 4. Density of final energy consumption for each individual heat pump system.

	Annual Heating/Cooling Consumption (kWh)	Final Energy Density (kWh/m ² a)
ASHP	2044140	112,89
GHP	1330561	73,48

In addition to this research, as a control scenario combination between GHP and ASHP was evaluated. Result has revealed that in that case 1,7% overall saving in cooling and heating consumption can be achieved. The comparison of final energy density of heat pump sequence control and each scenario was given on Table 5;

Table 5. Energy consumption values and savings for each applied scenario.

Energy consumption values and saving ratio for Scenario 1: Automatic Dimming Control			
	Annual Lighting Energy Consumption (kWh)	Density final energy consumption (kWh/m2a)	Saving (%)
Baseline	333668	18,43	
5% Dimming	327508	18,09	1,84
10% Dimming	327328	18,08	1,93
22% Dimming	328614	18,15	1,54
Energy consumption values and saving ratio for Scenario 2: Automatic Switching Control			
	Annual Lighting Energy Consumption (kWh)	Density final energy consumption (kWh/m2a)	Saving (%)
Baseline	333668	18,43	
2level Switching	326220	18,02	2,23
3level Switching	324906	18,01	2,62
Energy consumption values and saving ratio for Scenario 3: Time Switching Control			
	Annual lighting energy consumption (kWh)	Density final energy consumption (kWh/m2a)	Saving (%)
Baseline	333668	18,43	
Timer Switching Control	325706	17,03	2,38
Energy consumption values& saving ratio for Scenario 4: Loop Set-point Temperature Variation			
	Annual DHW Energy Consumption (kWh)	Final Energy Density (kWh/m2a)	Saving (%)
Baseline*	301210	29,80	-
Loop Set-point - 55°C	296296	29,31	1,4
Loop Set-point - 50°C	262003	25,92	13

(*In the baseline case, the main supply temperature is determined based on consumer requirement and heating generator.)

Energy consumption values and saving ratio for Scenario 5: DHW Demand Control			
	Annual DHW Energy Consumption (kWh)	Final Energy Density (kWh/m ² a)	Saving (%)
Baseline	301210	29,80	-
Demand Control	128335	12,70	57,4
Energy consumption values& saving ratio for Scenario 6: Solar Collector & Heat Pump Sequence			
	Annual DHW Energy Consumption (kWh)	Final Energy Density (kWh/m ² a)	Saving (%)
Baseline	301210	29,80	-
Demand Control	289216	28,61	4
Energy consumption values and saving ratio for Scenario 7: Predictive Zone Set Point Control			
	Annual Energy Consumption (kWh)	Final Energy Density (kWh/m ² a)	Saving (%)
Baseline	44,09	0,45	-
Predictive Set Point Control	34,34	0,35	22,1
Energy consumption values and saving ratio for Scenario 8: Heat Pump Sequence Control			
	Annual Heating/Cooling Consumption (kWh)	Final Energy Density (kWh/m ² a)	Saving (%)
Baseline (*Only GHP)	1330561	73,48	-
GHP + ASHP	1306800	72,16	1,79

3. Results

In this research, impact of configuration of various technologies and related control scenarios during the integration process was evaluated in terms of energy performance. Final results revealed that, possible strategies in lighting, domestic hot water and thermal system can reduce annual electricity and natural gas consumption of the building. Table 6 addresses together all applicable scenarios which have been evaluated in the previous sections. Within the integration of all mentioned scenarios, annual energy consumption can be reduced up to **10,45%**, which is equivalent of nearly **141,638 kgCO₂** per year.

IDENTIFICATION AND EVALUATION OF APPLICABLE TECHNOLOGIES' ENERGY SCENARIOS OF A BIG SCALE BUILDING

Hatice Sözer, Ergin Kükrer, Utku Simitli

Table 6. Evaluation of all scenarios.

	Scenarios	Savings (%)	Selected / Suggested
Lighting	1-Automatic Dimming Control	1,93	According to simulation results and related saving ratios, scenario 2: 3 level Automatic switching control strategy is selected to be applied.
	2-Automatic Switching Control	2,62	
	3-Occupancy Scheduled Control	2,38	
DHW	4-DHW Loop Set-Point Variation	13	Regarding DHW Scenarios, Combination of these three scenarios are suggested.
	5-DHW Demand Control	57,4	
	6-Solar Collector & HP Sequence	4	
Thermal	7-Predictive Set-Point Control	22,1	For common areas, predictive set-point control strategy and for the thermal system ground water source heat pump scenario is selected.
	8-Heat Pump Sequence	1,79	
Overall Estimated Energy Saving : 10,45%			

Acknowledgements

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2

EFFECT OF NON-UNIFORM WAKE ON THE EXERGY EFFICIENCY CALCULATIONS FOR WIND TURBINES

Emre Alpman

Abstract

This study investigates the effect of the non-uniform wake on the exergy efficiency calculations for small scale wind turbines. Performance predictions are made for a model small scale horizontal and vertical axis wind turbines using a steady and an unsteady methodologies. Numerical calculations showed that including the unsteady wake effects into the exergy efficiency calculations for vertical axis wind turbines affects the predictions of this quantity much more severely compared to the horizontal axis ones. A multiobjective aerodynamic optimization is also performed for small scale vertical axis wind turbines, which aims to maximize the mean value of the instantaneous exergy efficiency while minimizing its standard deviation about the mean. The results presented show the necessity of using a multi-parameter multiobjective optimization procedure to obtain a suitable aerodynamic design for sustainable wind energy production.

Keywords: *Exergy efficiency, wind turbine, nonlinear lifting line theory, double multiple stream tube method, unsteady wake, multiobjective optimization.*

1. Introduction

Satisfying its energy demands using the available natural energy sources is very important for a country to ensure sustainable development. For this purpose careful energy policy planning should be conducted in order to find the best alternatives among the available energy sources. Various multi-criteria decision making methodologies (Triantaphyllou, 2000; Kahraman, 2008) are basically employed for this purpose. In (Kahraman and Kaya, 2010) a fuzzy multi-criteria methodology was applied to select among different energy alternatives and wind energy was found to be the most *attractive* energy source in Turkey. Multi-criteria decision making analyses consisting of an integrated fuzzy VIKOR & AHP methodology (Kaya and Kahraman, 2010) and a modified fuzzy TOPSIS methodology (Kaya and Kahraman, 2011) also yielded wind energy as the most suitable renewable energy alternative. In (Deveci and Alpman, 2017)

a system dynamics approach was applied to construct a renewable energy policy for Turkey and wind energy was found to be the *dominant* energy source after 2019. Therefore, wind energy clearly has an important place in sustainable development. However growing energy demands made people question the reliability of wind energy (Ozgener and Ozgener, 2007). Exergy efficiency which defines the ratio of work extracted to the maximum possible useful work is one of the important indicators of sustainability (Rosen et al. 2008). Using the exergy balance equation (Çengel and Boles, 2002) exergy efficiency of horizontal and/or vertical axis wind turbines have been calculated in the literature (Rosen et al. 2008; Pope et al. 2010; Saravanan et al. 2011; Şahin et al. 2006). In these studies the downstream velocity at the wake of the rotor, which corresponds to the exit velocity of the control volume, was assumed to be uniform. However, this may not be the case in practice (Burton et al. 2011). Pope et al. (2010) showed the importance of defining a suitable downstream velocity by using four different definitions for this quantity.

This study includes effect of the non-uniform wake of small scale horizontal and vertical axis wind turbines on the exergy efficiency calculations. Here, an integral form of the exergy balance equation is used for this purpose. For horizontal axis turbines downstream velocity predictions are initially performed using blade element momentum theory (BEMT) (Burton et al. 2011), which is a popular method among wind turbine performance prediction methodologies for its speed and reasonable accuracy. As a result, it has been frequently employed for the aerodynamic design and optimization of horizontal axis wind turbines (Alpman et al. 2014). The results obtained using this method are compared to the results obtained using a nonlinear lifting line theory (Marten et al. 2015). Being a vortex method, nonlinear lifting line theory could include unsteady effects and could yield better predictions than the BEMT. For the vertical axis wind turbines the corresponding predictions are first obtained using double multiple stream tube model (Paraschivoiu, 2002) and again they are compared with nonlinear lifting line predictions. The necessary numerical predictions will be performed using the open source wind turbine design and analysis software QBlade (<http://q-blade.org/>) which contains all of the methods described above.

Exergy efficiency calculations are performed for three bladed horizontal and vertical axis wind turbines. The blades of the horizontal turbines studied are obtained using the design methodology described in chapter 3 of (Burton et al. 2011). The vertical axis turbines will have untwisted and untapered blades. Geometric properties of these turbines will be selected such that they will have the same swept area and rotor solidity with the horizontal axis ones. Since exergy efficiency is one of the key indicators of sustainability (Rosen et al., 2008) its accurate calculation is very important for sustainable wind energy production. The study in this paper basically aims to improve the calculation of this quantity for wind turbines.

2. Methodology

The exergy balance for a control volume with one inlet and one exit can be written as (Pope et al. 2010):

$$\dot{Ex}_{in} - \dot{Ex}_{out} - \dot{W} - \dot{Ex}_{dest} = 0 \quad (1)$$

Here, \dot{Ex}_{in} and \dot{Ex}_{out} are rates of exergy entering and leaving the control volume, \dot{W} is the rate of work extracted and \dot{Ex}_{dest} is the rate of exergy destruction inside the control volume due to irreversibilities (Pope et al. 2010; Şahin et al. 2006). In the case of a control volume around a wind turbine the term \dot{W} corresponds to the power produced by the turbine. The corresponding exergy efficiency is then calculated by

$$\eta_{ex} = \dot{W} / (\dot{Ex}_{in} - \dot{Ex}_{out}) \quad (2)$$

Typically the rate of exergy contains physical and the kinetic energy components (Pope et al. 2010). However, in this study the physical component is assumed to remain constant therefore, only the exergy of the kinetic energy is considered. Here, the power produced by the turbine and the velocity in the wake are predicted using the QBlade software. For the vertical axis wind turbine analyzed in this extended abstract, this procedure is done in two ways. First the performance of the turbine is obtained using the double multiple stream tube model (Paraschivoiu, 2002). The mass flow rate through the turbine was calculated by multiplying the average turbine inlet velocity with the swept area of the rotor. The exit kinetic energy is then calculated by multiplying this mass flow rate with the average of the square of the wake velocity. In the second approach turbine performance is obtained using a nonlinear lifting line theory (Marten et al. 2015). Since this method could yield the velocity distribution on any plane selected by the user, a square prism shaped control volume is defined around the turbine. The side of the cross-section of this volume is 2.5 times the diameter of the rotor and it extends one rotor diameter upstream and downstream of the rotor cylinder. The rates of exergy entering or leaving the control volume are calculated using the following integral:

$$\int_A \rho \frac{u^3}{2} dA \quad (3)$$

Where u is the velocity component normal to the area element dA on the inlet or exit plane. The turbine performance presented here is obtained at a steady wind speed of 5 m/s and a rotor tip speed ratio of 3.

3. Results and Discussion

The vertical axis wind turbine analysed here composed of three blades with a constant CLARK Y 11.7% smoothed airfoil section (https://mselig.ae.illinois.edu/ads/coord_database.html). The rotor has a height of 4.5m, radius of 2.29m and blades are swept by 23.01 degrees. The blades of the turbine are displayed in Figure 1. This turbine was the one which yielded maximum power production after the optimizations presented in (Usanmaz and Alpman, 2017). Figure 2 displays the turbine power and wake speed for the turbine predicted using double multiple stream tube method. Using these predictions and following the procedure described in the Methodology section the exergy efficiency was calculated to be 0.822.

Figure 1. Blades of the vertical axis wind turbine

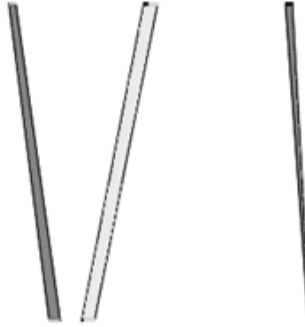
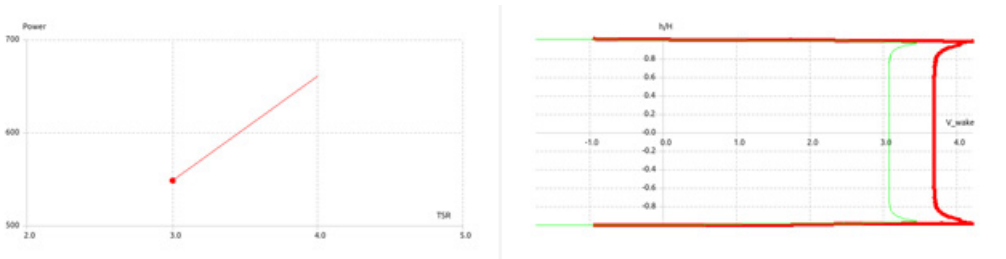


Figure 2. Power and wake velocity predictions by double multiple stream tube method



In order to compute the exergy efficiency via the nonlinear lifting line theory, unsteady performance predictions are performed for 10 rotor revolutions and velocity field is saved at each time step which corresponds to five degrees of blade movement. The velocity distribution on the exit plane at the final time step is displayed in Figure 3. The exergy efficiency is then computed using the integral given above after the quasi-steady conditions are reached, which is achieved after the 450th time step. Figure 4 shows the exergy efficiency values computed at every 10th

time step after the 450th along with their mean value which was obtained to be 0.677. It is clear that once the unsteady wake effects are introduced to the computations, the predicted exergy efficiency values may show huge variations and even the mean value of these values is not in agreement with the one calculated using the double multiple stream tube method.

The studied horizontal axis wind turbine also has three blades and the same sweep area with the vertical axis one presented above. The blades of this turbine, which are composed of SG6042 airfoil section (<http://airfoiltools.com/airfoil/details?airfoil=sg6042-il>), can be seen from Figure 5. The blades are designed following the practical blade design procedure described in Chapter 3 of (Burton et al. 2011). Here, the blades are designed for a design tip speed ratio of 5.

The steady analysis for this turbine type is performed using BEMT (Burton et al. 2011) for a. Predicted rotor power and annulus averaged axial induction factor for a tip speed ratio of 3 are displayed in Figure 6. Using this induction factor flow velocity across the rotor disk was obtained and integrated along the rotor radius in order to compute the mass flow rate through the rotor. The velocity at the wake was then computed assuming that the axial induction factor at the wake is twice the average of the axial induction factor displayed in Figure 6. Using these predictions the exergy efficiency was calculated to be 0.345.

Figure 3. Velocity distribution on the exit plane at the final time step

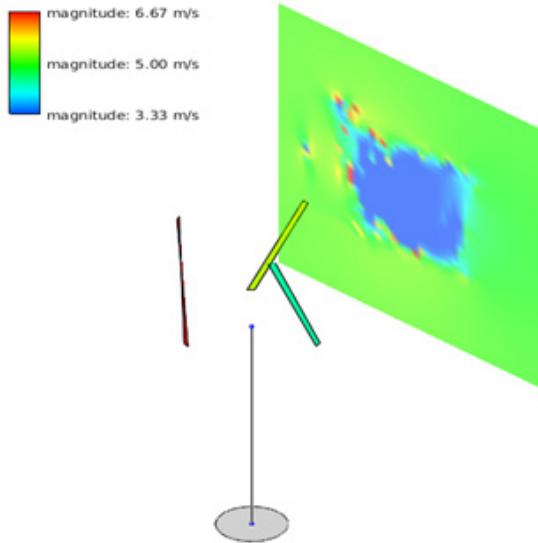
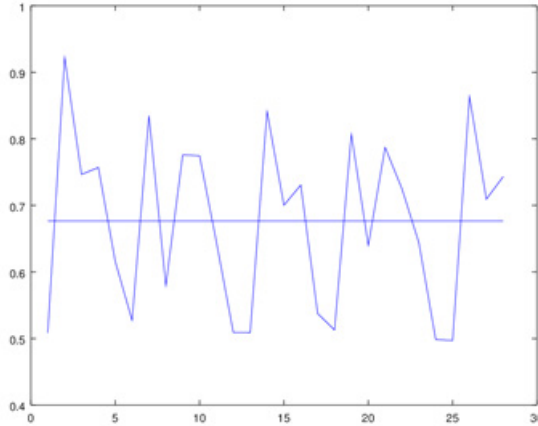


Figure 4. Exergy efficiency values (vertical axis) at different time steps

As it was done for the vertical axis wind turbine analysis, the unsteady analyses for the horizontal axis turbine are performed using the nonlinear lifting line theory. Again predictions are performed for 10 rotor revolutions and velocity field at a vertical plane located one diameter downstream of the rotor is recorded at every time step. The velocity distribution on this plane at the final time step is displayed in Figure 7. The exergy efficiency values computed at every 5th time step after steady conditions are reached, along with their mean value which was obtained to be 0.310 are shown in Figure 8. Once the vertical axis scale of this figure is compared with that of Figure 4 is compared, one can easily see that the exergy efficiency variations about the mean value for the horizontal axis turbines are much smaller than the vertical axis ones. For both turbine types, unsteady analyses predicted a lower exergy efficiency value than the steady analysis, however, the difference between them is much smaller for horizontal axis one. Considering the results presented one can easily conclude that the unsteady wake of a vertical axis wind turbine has a much more severe effect on the exergy efficiency predictions compared to horizontal axis wind turbines.

Figure 5. Blades of the horizontal axis wind turbine

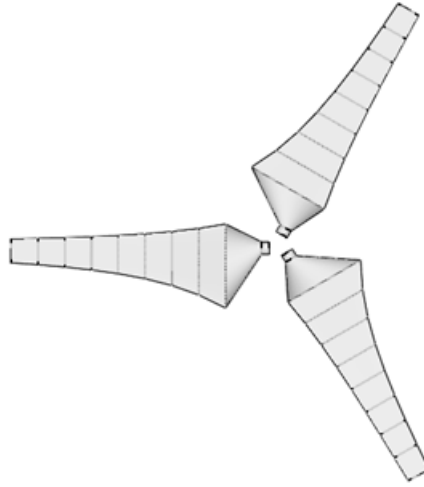


Figure 6. Power and wake velocity predictions by BEMT

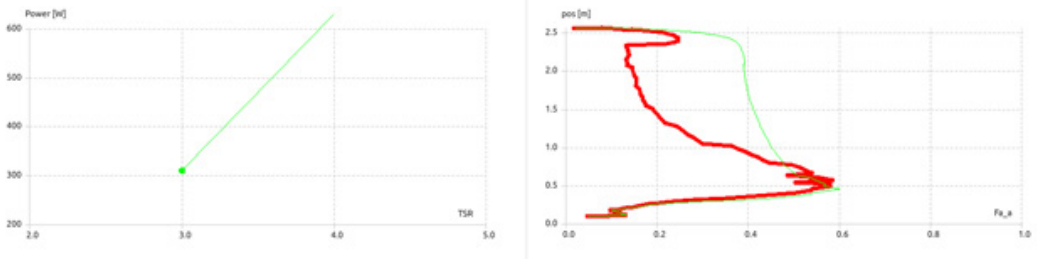


Figure 7. Velocity distribution on the exit plane at the final time step

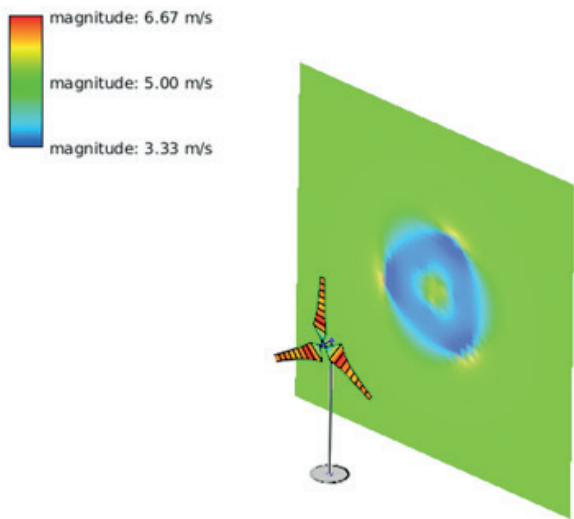
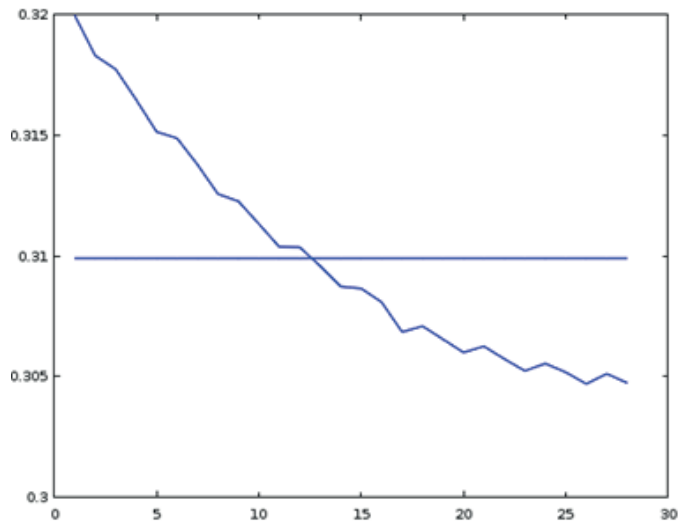


Figure 8. Exergy efficiency values (horizontal axis) at different time steps



Optimization of Small Scale Vertical Axis Wind Turbines for Maximum Exergy Efficiency

Among the two types of small scale wind turbines analyzed, the vertical axis ones are more suitable for urban environments because ones thanks to their ability to accept wind from any direction. However, it was clearly shown in the previous section that the exergy efficiency of vertical axis wind turbines may show huge variations mainly because of their unsteady wake and these variations will negatively affect the rate of useful work obtained from the turbine (Pope, et al. 2010; Şahin et al. 2006). Therefore a multiobjective aerodynamic optimization was performed for small scale vertical axis wind turbines which aims to maximize the mean value of the unsteady exergy efficiency variations while at the same time it tries to minimize the standard deviation of them. As it was done in (Usanmaz and Alpman, 2017), the rotor height, rotor radius and the helix angle of the blades are selected as the optimization parameters while the chord length, airfoil section and the number of blades are kept fixed. Here, the rotor has three blades with a chord length of 0.1m and NACA 0021 airfoil section. The rotor height is allowed to change between 2m and 4m while the rotor radius varies between 1m and 2m. The range for helix angle is set to be between 0 and 60 degrees. The corresponding multi-objective optimization studies are performed using the NSGA-II algorithm (Deb et al. 2002). An open source NSGA-II Matlab code shared at (<http://yarpiz.com/56/ypea120-nsga2>) is used for this purpose. In order to predict the fitness functions during the optimizations a Matlab code (http://www3.ntu.edu.sg/home/egbhuang/elm_codes.html) which is based on the basic ELM algorithm (Huang et al. 2006) is employed. In order to train the corresponding neural network a database consisting of 25 different designs is constructed using the Sobol design of experiment method of the GNU Scientific Library (<https://www.gnu.org/software/gsl/>). Here 20 of these 25 designs are used for training while the remaining 5 are used for testing. The number 20 corresponds to the number of designs necessary to construct a cubic response surface (Cavazutti, 2013). The fitness functions of the designs in this database are computed using the nonlinear lifting line method of the QBlade software in the same way as it was done in the previous section.

The resulting database consisting of 25 different designs is given in Table 1. In this table H , R , θ , η_{ex} , and $std(\eta_{ex})$ denote rotor height, rotor radius, helix angle, mean exergy efficiency and the standard deviation about the mean exergy efficiency, respectively. The turbine performances presented here are obtained at a steady wind speed of 5 m/s and a rotor tip speed ratio of 3.

In order to find a suitable neural network for the predictions, the number of neurons in the hidden layer is varied between 1 and 20. Here, for each number of neurons, training procedure is repeated 100 times and the network yielding the minimum error is selected for each fitness function. The NSGA-II code then uses the selected networks for further predictions. Since the NSGA-II algorithm aims to minimize the objectives, the first objective was redefined as the reciprocal of the mean exergy efficiency.

Table 1. Database constructed for neural network training

H (m)	R(m)	θ (°)	η_{ex}	std (η_{ex})
3.0000	1.5000	30.000	0.7118	0.09168
3.5000	1.2500	45.000	0.6798	0.09133
2.5000	1.7500	15.000	0.7307	0.07972
2.7500	1.3750	37.500	0.6974	0.09277
3.7500	1.8750	7.500	0.6260	0.07236
3.2500	1.1250	22.500	0.6693	0.11207
2.2500	1.6250	52.500	0.6927	0.09714
2.3750	1.3125	18.750	0.6913	0.10304
3.3750	1.8125	48.750	0.6954	0.09723
3.8750	1.0625	33.750	0.6524	0.11284
2.8750	1.5625	3.750	0.7095	0.08621
2.6250	1.1875	56.250	0.6693	0.09639
3.6250	1.6875	26.250	0.7111	0.08778
3.1250	1.4375	11.250	0.7044	0.08964
2.1250	1.9375	41.250	0.7223	0.09318
2.1875	1.4688	50.625	0.6992	0.09566
3.1875	1.9688	20.625	0.7371	0.08522
3.6875	1.2188	5.625	0.6614	0.09473
2.6875	1.7188	35.625	0.7190	0.08572
2.9375	1.0938	28.125	0.6651	0.11147
3.9375	1.5938	58.125	0.6853	0.10329
3.4375	1.3438	43.125	0.6872	0.08904
2.4375	1.8438	13.125	0.7274	0.08631
2.3125	1.1562	31.875	0.6691	0.10420
3.3125	1.6562	1.875	0.7005	0.08245

Multiobjective optimizations are performed for 300 generations for a population consisting of 50 individuals. Figure 9 shows the fitness functions of the individual in the population at different generations. It is clear that the distribution hardly changes after the 100th generation. Therefore, one can assume that the optimization algorithm has converged. Also one can note that after the 100th generation all the individuals are non-dominated, hence they form the Pareto front. It is also clear from the figure that once we try decrease the standard deviation in the exergy efficiency calculations the mean value of this quantity also tend to decrease.

According to Figure 9 the resulting Pareto front is composed of two pieces. Since any point on a Pareto front represents an optimum design, one has to use a selection strategy to pick one or more of these. In this study the designs which are at the extremes of the individual Pareto front pieces are selected as examples. The geometries and the corresponding fitness function values for these four designs are displayed in Table 2. Comparing the designs in the second and the third rows of this table indicates that increasing the helix angle helps increase the mean exergy efficiency without effectively increasing its standard deviation. However, the table also shows a decrease in the aspect ratio (ratio of rotor height to rotor diameter) and the solidity of the rotor between these designs. It is therefore evident that a multiobjective and multi-parameter optimization strategy is necessary in order to seek suitable turbine geometries for better exergy efficiency.

Figure 9. Objectives of the individuals at different generations

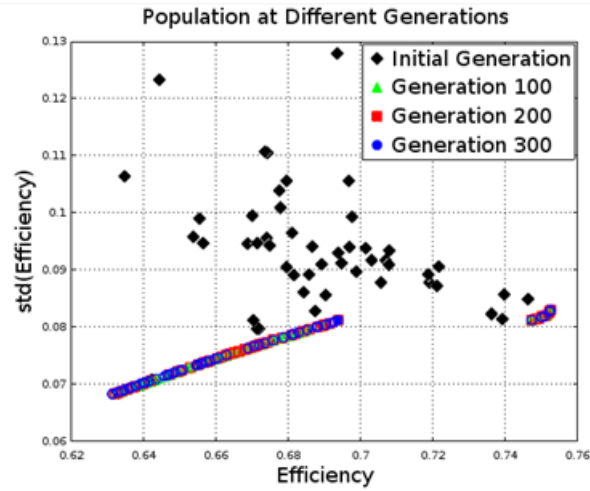


Table 2. Four designs selected from the Pareto front

Design number	H (m)	R(m)	θ (°)	η_{ex}	std (η_{ex})
1	2.8762	1.9263	22.9844	0.7526	0.0830
2	2.7065	1.9251	27.8039	0.7473	0.0812
3	3.5324	1.6999	8.3173	0.6938	0.0812
4	3.9226	1.6877	7.5810	0.6313	0.0683

In order to compare the aerodynamic performances of the second and the third designs presented in Table 2, aerodynamic predictions for them are obtained using QBlade. Figure 10 shows the instantaneous power predictions for these second and third designs. It is interesting to note from this figure that even though the exergy efficiency of the third design was predicted to be lower than the second design, the mean power of the former is predicted to be higher than the latter. In addition to this, the amplitude of the power oscillations of the third design is clearly higher than the second design in Figure 10 although the standard deviations in exergy efficiency predictions for these designs were nearly identical. Therefore, one can conclude that power predictions alone would not help identify the exergy efficiency of vertical axis wind turbines. In order to further investigate this, the axial velocity distributions (in the freestream wind direction) at the wakes of these two designs are plotted in Figure 11. Here, the image on the left belongs to design 2 while the other belongs to design 3. It is evident that the velocity deficit at the wake of the third design is considerably higher than the second design (as expected) which means that the difference in the inlet and exit kinetic energy rates (denominator of equation 2) will also be higher in addition to the produced power.

Figure 10. Power Predictions for design 2 and 3

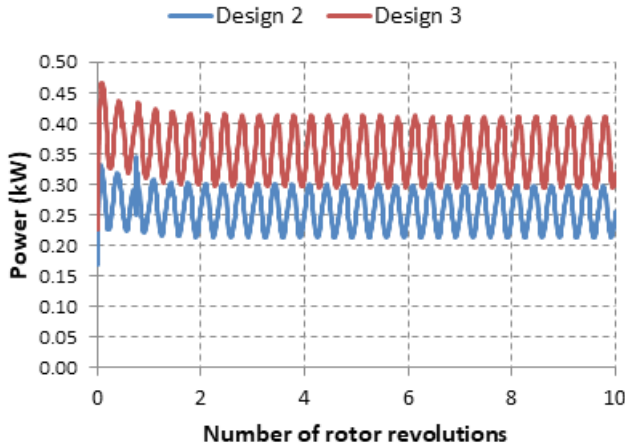
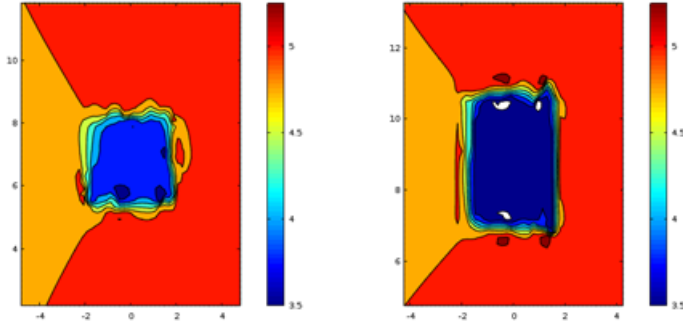


Figure 11. Velocity distribution at the wake of design 2 (left) and design 3 (right)



4. Conclusion

In this study the effect of unsteady wake on the exergy efficiency computations of small scale horizontal and vertical axis wind turbines were investigated. The analyzed turbines had the same sweep area and were operated at the same wind speed and tip speed ratio. Steady and unsteady performance predictions were performed for both turbine types. Here, blade element momentum theory was used for horizontal axis type while double multiple stream tube method was used for the other. Nonlinear lifting line method was used for unsteady analyses of both types. The computations clearly showed that when the unsteady wake effects are introduced to the predictions for the vertical axis turbine, the results showed huge variations and even the mean value of those variations did not agree with the steady state predictions. However this effect was much less pronounced for the horizontal axis one where the steady and unsteady exergy efficiency predictions were in closer agreement.

In order to improve the exergy efficiency performance of vertical axis wind turbines, a multi-objective aerodynamic optimization was also performed for them which aimed to maximize the mean of the unsteady exergy efficiency predictions while minimizing the standard deviation of this quantity about the mean. The results of the optimization showed that due to the unsteady wake downstream of a vertical axis wind turbine even in steady wind conditions, standard deviation in the instantaneous exergy efficiency might increase when one attempts to increase its mean value. A further investigation on four designs selected from the obtained Pareto front showed that unsteady power predictions alone would not help predict the exergy efficiency of the turbines. It is recommended to include other design parameters like blade chord length and airfoil section to the optimization studies as a future work.

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3

PERFORMANCE EVALUATION OF REFRIGERANTS USED IN A FLASH-SYSTEM REFRIGERATION WITH REGARDING ENVIRONMENTAL ASPECTS

Ebru Mançuhan, Barış Yılmaz, M. Kemal Sevindir, Deniz Yılmaz

Abstract

Conventional refrigerants such as chlorofluorocarbons (CFC) and hydro-chlorofluorocarbons (HCFC) are being phased out worldwide because of the risk of ozone layer depletion (ODP) and global warming potential (GWP) considerations. Natural refrigerants such as ammonia, propane, carbon dioxide, and other natural refrigerants have drawn increased attention as refrigerants to protect environment. Flash refrigeration systems are recently utilized to reach low and very-low temperature levels.

In the present study, a thermodynamic model described a flash-system is implemented in Engineering Equation Solver (EES) in order to examine the effects of different operating parameters on the system performance. In addition, in order to realize an environmentally friendly refrigeration flash-system both natural (NH₃ and R290) and synthetic (R134a and R404A) refrigerants are examined. The operating conditions are chosen to represent low and medium cooling temperature applications. In addition, the optimum intermediate pressure values (P_{int}) which maximize the performance of the system are determined for each studied refrigerants. Furthermore, mass flow rate requirements for various refrigerants are computed and compared at different evaporation capacities of evaporators. An environmental sustainability has been performed for the leakage of refrigerants in terms of ODP and GWP for all studied refrigerants.

Keywords: Flash System, Global Warming Potential, Ozone Depletion Potential, Natural Refrigerants, COP

1. Introduction

Chlorofluorocarbons (CFC) and hydro-chlorofluorocarbons (HCFC) are being replaced by natural refrigerants due to the environmental considerations. Applications with natural refrigerants such as ammonia, propane, carbon dioxide etc. are increasingly preferred in low temperature refrigeration applications. Mainly, In order to decide the environmentally friendly

and efficient refrigerant in the application, along with the design conditions, other important characteristics such as toxicity, flammability etc. and environmental traces in terms of ODP and GWP should be also taken into account.

Improvement in performance of a refrigeration cycle can be usually done by lowering the compressor power consumption and thereby reducing the difference between condenser and evaporator pressures or increasing the condenser heat rejection capacity. In addition, intercooling is one of the commonly preferred method in order to increase the performances of the two-stage refrigeration systems. Intercooling can be accomplished by throttling the refrigerant's liquid from the condenser into a flash tank. A flash tank is mainly utilized to separate the liquid and vapor phases of the working fluid. It de-superheats the discharge gas from the low pressure compressor. In addition, a flash tank cools the liquid from the condenser to the saturated temperature corresponding to the intermediate pressure. The power consumption of the system decreases due to the compression of flash gas only from the intermediate pressure to condensing pressure. On the other hand, the cooling capacity increases compared to a single cycle system (Minh et al. 2006). There are many studies in literature using intercooling between the stages to improve the performance of the cycle. (Mbarek et al. 2016; Jiang et al. 2016; Cho et al. 2009; Yuan and Xia 2008; Arora and Dhar, 1971).

Mbarek et al. (2016) performed thermodynamic analysis of a R134a cascade refrigeration cycle for three different configurations. A flash tank is integrated with an internal heat exchanger for intercooling. The location of the flash tank in the cycle is an important parameter for calculation of the cycle performance. The cycle performances and the working flexibility at different conditions are considered to choose the best system configuration. Cho et al. (2009) developed a cycle simulation model to predict the performances of the basic and advanced CO₂ refrigeration cycles. For the basic CO₂ cycle, the predicted data from the model was validated by comparing with the experimental data at the standard cooling conditions. In their study, three different advanced CO₂ refrigeration cycle options were considered. First option was a single-stage CO₂ cycle with an expander. Second one was a two-stage CO₂ cycle with an intercooler. Finally, a two-stage CO₂ cycle with a vapour injection was investigated. They concluded that second case yielded a 13.1% improvement of the COP and third case resulted in a 18% improvement of the COP with a flash tank located between the two stages of expansion.

Jiang et al. (2016) analyzed the influences of the inter-stage sub-cooling parameters (ϵ) and the compressor efficiencies on optimum intermediate pressure ($P_{m,opt}$) for six types of two-stage refrigeration cycles using R22 and ammonia as the refrigerants. Results showed that, for the ideal cycles, the ϵ was a critical influence factor on the $P_{m,opt}$ in addition to the condensing and evaporating conditions. However for the real cycles, both the ϵ and the efficiencies of the two compressors affected the $P_{m,opt}$ considerably. Two revised formulas were proposed to estimate $P_{m,opt}$ for the ideal and real cycles, respectively. Yuan and Xia (2008) compared two

heat pump systems; one equipped with a flash-tank and the other with a sub-cooler. At low ambient temperatures, the efficiency of the former heat pump system is observed better than the system with sub-cooler. Furthermore, the flash-tank system is less complicated. Arora and Dhar (1971) illustrated that the optimum intermediate pressure level equals to the geometric average of the corresponding evaporation and condensation pressures. However, when the flash intercooler is added to the cycle, an important difference between the calculated mean and the actual intermediate pressure has been observed. In literature, using the thermodynamics models, better performance of the two-stage cycle with flash tank than the single-stage cycle is shown. However performance of flash system depends significantly on the intermediate pressure and temperature (Gupta and Prasad 1984, Zubair et al. 1995, Tiedeman et al. 2003.) Therefore, it is important to determine the optimum intermediate pressure for different operating conditions to improve the performance of two stage flash-system.

Recently, the flash refrigeration systems are applied to reach low and very-low evaporation temperature levels. In design of such systems, the temperature levels in low and high temperature cycles as well as the optimum intermediate pressure values (P_{int}) which maximize the coefficient of performance (COP) are important parameters. In addition, it is required to investigate and improve the performance of refrigeration systems using natural refrigerants to compete with the conventional systems.

The evolution and progression of refrigerants are reviewed in several works, Bolaji and Huan 20013 and Calm 2008. The reveal of first Ozone Depletion Potential (ODP) and then Global Warming Potential (GWP) concepts are presented in detail within an historical frame. The former concept, ODP, started to be discussed at 1990s and the latter one became popular about 2010s. Nowadays, the aim is to utilize refrigerants having zero/low ODP and as much as possible low GWP in refrigeration systems.

In the present study, the optimum intermediate pressure values (P_{int}) which maximize the COPs were determined with different operating conditions of the various refrigerants to realize an energy efficient and environmentally friendly flash-system. For this purpose, influences of various evaporation temperatures, T_L , ranging from $-40\text{ }^{\circ}\text{C}$, to $10\text{ }^{\circ}\text{C}$, high condensation temperature, T_H , varying between $30\text{ }^{\circ}\text{C}$ and $50\text{ }^{\circ}\text{C}$ and intermediate pressure, P_{int} , on the system COP with different refrigerants were calculated. At a given low and high temperature values, the corresponding low and high pressure values were calculated. In addition, the optimum intermediate pressure values (P_{int}) which maximize the COPs were determined for each studied refrigerants, namely NH_3 , R290, R134a and R404A. Furthermore, mass flow rate requirements of the system for different evaporation capacity of the evaporators, Q_{evap} , were computed and compared for various refrigerants. Based on computed mass flow rates, the effect of chosen refrigerant on environment was evaluated in terms of ODP and GWP values for a flash system.

Thermodynamic Analysis of the Flash-System

The schematic diagram of a two stage flash-system cycle is shown in Figure 1a. Among the main components of this cycle are the first stage compressor (low temperature cycle), evaporator, expansion valve 1, the second stage compressor (high temperature cycle), condenser, expansion valve 2. A flash tank is located between the high and low temperature cycles. The use of flash tank provides reducing the mass flow rate of working fluid sent to the evaporator. Therefore, optimizing of the evaporator size can be possible in refrigeration applications. In addition, the flash tank between these cycles' supplies saturated vapor to the compressor stage working between intermediate and high pressure components and saturated liquid to the expansion valve of the bottoming cycle.

As seen in Figure 1 (a), the gas leaving the first stage compressor at state (3) flows through the flash tank. The warm gas enhances the generation of additional flash gas. So, the refrigerants leave the expansion valve 1 in low quality at state (7). Saturated vapor obtained from the flash tank at state (4) is directed to the compressor of the second stage. This cycle having two stages of both compression and expansion is utilized to improve the energy efficiency and thereby decrease the power consumption. This improvement is accomplished by the decrease in the exergy losses during the expansion processes.

System has three different pressure levels as seen from T-s diagram in Figure 1b. They are evaporation pressures ($P_1=P_2$), condensation pressures ($P_5=P_6$) and intermediate pressures ($P_{int}=P_3=P_4=P_7=P_8$) between the two compression stages. The pressure between the high and low temperature cycles is a design parameter which plays an important role in order to determine the coefficient of performance (COP) of the overall system (Cengel and Boles et al.,).

The thermodynamic model of the two stage flash-system is developed using first law of thermodynamics. Mass and energy equations are derived for both low and high temperature cycles. In this study, considering the schematic and the state points of Figure 1a and 1b, the following equations are developed for the analysis. In the analysis, following assumptions are taken into account;

- heat gain and losses of system components and pressure losses in all components of system are neglected.
- potential and kinetic energy changes are neglected,
- isentropic compressor efficiencies of 0.72 both low and high temperatures cycles are assumed,
- isenthalpic expansion of refrigerants in expansion valves,

- saturated vapor state at the exit of evaporator ($\Delta T_{\text{sup}}=0$), saturated liquid state at the exit of condenser ($\Delta T_{\text{sub}}=0$).

Numerical calculations are performed using well-known Engineering Equation Solver (EES) software. EES is a general equation-solving program that can numerically solve coupled non-linear algebraic, differential equations and optimization problems. The thermo-physical properties of the refrigerants (NH₃, R290 R134a and R404A) specified in this study is obtained using EES which has property database of numerous refrigerants.

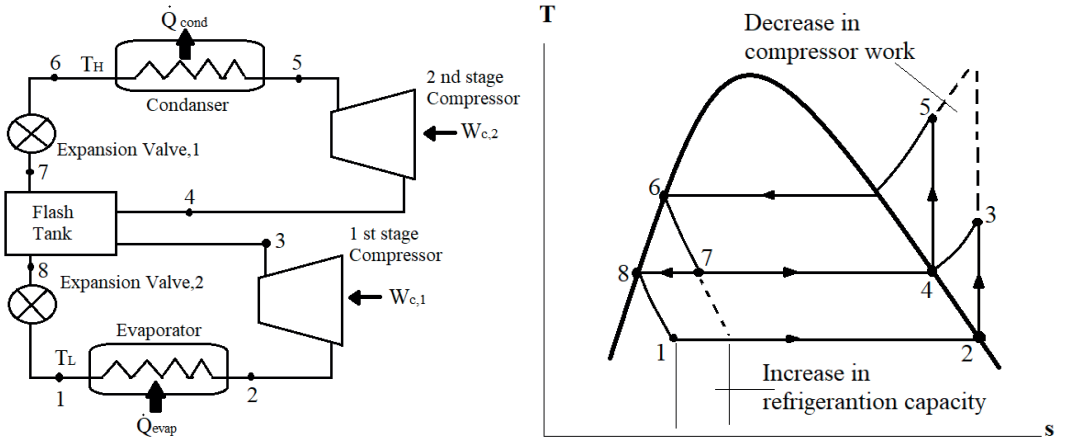


Figure 1. Schematic view (a) and T-s diagram (b) of the two-stage flash refrigeration system

The mathematical model of the two stage flash-system has been developed using first law of thermodynamics. The derived equations are given below;

The capacity of the evaporator of LTC is defined as

$$\dot{Q}_{\text{evap}} = \dot{m}_{\text{evap}}(h_2 - h_1) \quad (1)$$

Compressor power consumption for LTC is

$$\dot{W}_{\text{comp1}} = \dot{m}_{\text{evap}}(h_3 - h_2) \quad (2)$$

Similarly, compressor power consumption for HTC is

$$\dot{W}_{\text{omp2}} = \dot{m}_{\text{cond}}(h_5 - h_4) \quad (3)$$

Energy balance for flash chamber

$$\dot{Q}_{Flash\ tank} = \dot{m}_{cond}(h_7-h_4) = \dot{m}_{evap}(h_3-h_8) \quad (4)$$

The mass flow ratio is determined by using Equation 4:

$$\frac{\dot{m}_{cond}}{\dot{m}_{evap}} = \frac{(h_7-h_4)}{(h_8-h_3)} \quad (5)$$

The rate of heat rejection by the condenser of HTC is defined as

$$\dot{Q}_{cond} = \dot{m}_{cond}(h_5-h_6) \quad (6)$$

And finally, the overall COP of the flash- system is determined by

$$COP = \frac{\dot{Q}_{evap}}{\dot{W}_{comp1} + \dot{W}_{comp2}} = \frac{\dot{m}_{evap}(h_2-h_1)}{\dot{m}_{evap}(h_3-h_2) + \dot{m}_{cond}(h_5-h_4)} \quad (7)$$

2. Environmental Analysis

Two major parameters GWP and ODP are used in evaluating the trace of refrigerants on the environment. One kg of R404A has a GWP of 3800, one kg of R134A has a GWP of 1370, one kg of NH₃ has a GWP of 1 and one kg of R290 has a GWP of 20. In addition, ODP value is zero for R404A, R134a, NH₃ and R290 (Lemmon et al.). These values showed that true selection of environmentally friendly refrigerant is crucial to reduce the harmful effects of them on the environment and to decrease contribution to the global warming. The properties of refrigerants considered in this study can be seen in Table 1.

In the present study, two natural and two synthetic refrigerants have been examined. In the first natural refrigeration case, NH₃ is utilized as the refrigerant of the flash system. Using ammonia in low temperature cycle is not proposed since below -35 °C, it has a vapour pressure lower than atmospheric pressure which may cause air leakage into the system besides it is a toxic and flammable refrigerant. Propane is the second natural refrigeration case. Propane (codded as R290) has excellent thermodynamic properties. It is cheap and universally available. Since propane is a non-toxic refrigerant it is the major reason for selecting propane as the refrigerant over ammonia. However, propane is highly flammable serious concern and hence safe design and operating practice is of extreme importance.

For the synthetic refrigerant cases two refrigerants, R404A and R134a, are chosen since they are currently used more commonly in commercial and industrial refrigeration applications. Particularly, R134a is suitable for commercial refrigeration plants because of its prominent thermo-physical properties. It is non-flammable and nontoxic. However due to the high GWP values of R404A and R134a, they would be totally phased out by 2020 in developing countries

(Montreal Protocol) and its amendments from the United Nations Environment Program (UNEP, 1987). Therefore, the effect of the different refrigerants and their performances, especially natural ones, on the flash-system performance and the environment should be examined in detail.

Table 1. Thermo-physical and environmental properties of refrigerants (UNEP and Lemmon et al., 2007)

	R717 (NH ₃)	R134a	R404A	R290
Classification of refrigerants	Natural	HFC	HFC	HC
Critical Temperature (°C)	132.3	101.1	72	96.7
Critical Pressure (MPa)	11.33	4.05	3.731	4.25
ODP	0	0	0	0
GWP	1	1370	3700	~20

3. Results and Discussion

Influence of several parameters on the flash system performance is investigated using the developed mathematical method. Initially, the effect of intermediate pressure on the system performance has been examined. Secondly, influence of different operating conditions in terms of evaporation (T_L) and condensation (T_H) temperatures is considered. The evaporator capacity also has been varied for scaling up the system. Finally, the evaluation of selected refrigerants with regard to environmental protection is presented.

Effect of the optimized intermediate pressure of performance

The corresponding optimum intermediate pressure values are calculated to maximize the COP values at a given evaporation temperature value. In these calculations, the evaporation temperature of low temperature cycle (T_L) is varied between -40 °C and -10 °C by keeping the condensing temperature of high temperature cycle constant. ($T_H = 50$ °C). The degree of subcooling and superheat is assumed to be 0 °C. In addition, the evaporation capacity is selected to be 5250 W as in a medium scale supermarket.

The calculated optimum intermediate, evaporation and condensation pressures with different refrigerants can be seen in Table 2. The evaporation pressure or the low pressure ($P_1 = P_2 = P_L$) and the condensation pressure or the high pressure ($P_5 = P_6 = P_H$) values are determined for different refrigerants. These pressure levels depend on the temperatures of both the conditioned space and the ambient conditions. Likewise, the optimum intermediate pressure values (P_{int})

which maximize the COPs have to be calculated for each selected refrigerants, NH₃, R290, R404a and R134a.

Table 2. Optimum intermediate pressure values (P_{int}) which maximize the COP

		T_L (°C)						
		-40	-35	-30	-25	-20	-15	-10
NH ₃	P_L (kPa)	-	-	-	119.4	151.5	190.1	236.2
	P_{int} (kPa)	-	-	-	618.9	682.7	750.1	821.2
	COP	-	-	-	1.66	1.83	2.03	2.25
	P_H (kPa)	2253						
R134a	P_L (kPa)	-	-	-	-	106.5	132.8	164.1
	P_{int} (kPa)	-	-	-	-	526.2	564.2	604.3
	COP	-	-	-	-	1.75	1.93	2.14
	P_H (kPa)	1318						
R404A	P_L (kPa)	105.1	132.7	165.6	204.5	250.1	303.0	364.1
	P_{int} (kPa)	864.0	915.2	968.8	1025	1084	1146	1211
	COP	1.04	1.14	1.25	1.38	1.52	1.69	1.88
	P_H (kPa)	2295						
R290	P_L (kPa)	-	111.0	137.2	167.8	203.4	244.5	291.6
	P_{int} (kPa)	-	663.1	703.7	746.3	790.9	837.8	886.8
	COP	-	1.30	1.42	1.56	1.71	1.89	2.1
	P_H (kPa)	1867						

Effect of the evaporation temperature (T_L) on the maximized COP

The effect of evaporation temperatures on the COP for different refrigerants is investigated in this part. All refrigerants can be used at the evaporation temperatures -20 °C, -15 °C and -10 °C. Since -20 °C is the lowest applicable temperature for all refrigerants. Therefore, this temperature is chosen as a reference point for comparison. As shown in Figure 3, decreasing the evaporating temperature from -10 °C to -20 °C reduces the COPs of all refrigerants. NH₃ has the highest COP value (1.83) while R404A has the lowest COP value (1.52). R134a and R290 have the maximum COP values of 1.75 and 1.71, respectively. As a result, natural refrigerant R290 performed as good as synthetic refrigerant R134a concerning the COP. On the other hand, R290 has the best environmental performance as compared to the other refrigerants such as R134a and R404A (Table 3).

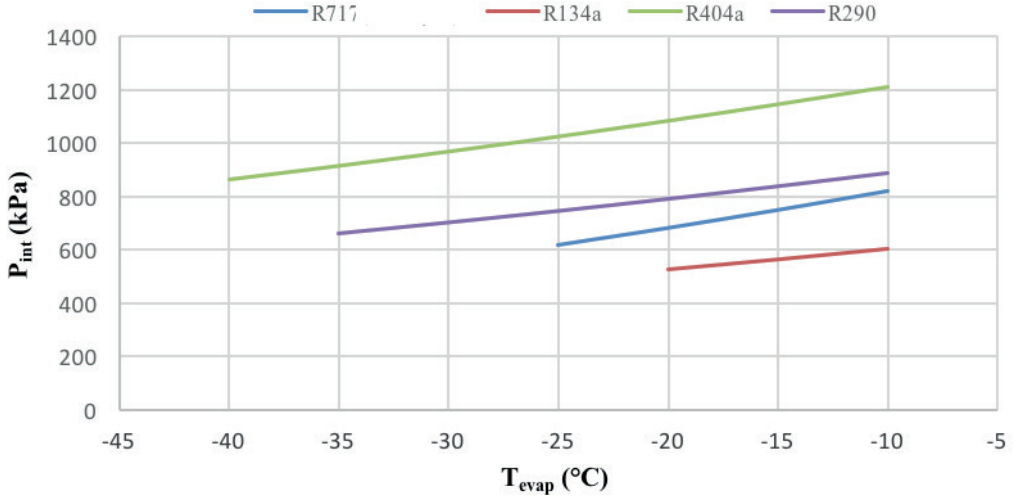


Figure 2: Optimum intermediate pressure values versus evaporation temperature

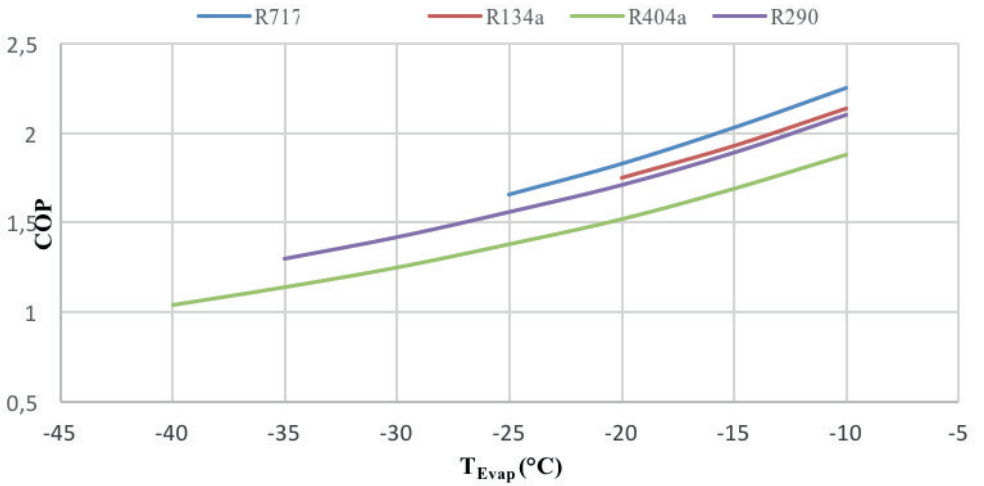


Figure 3: Effect of Evaporation Temperature on Maximized COP

Effect of condensation temperature (T_H) on COP

The variation of COP with respect to condensation temperatures from 30 °C to 50 °C is calculated. It is revealed that increasing the condensation temperature reduces the COPs for all studied refrigerants (Figure 4). As a common practice, the refrigerant condensation temperature

is chosen to be 40 °C and the performance of all selected refrigerants is compared at this temperature. The highest COP (2.14) is calculated for the natural refrigerant NH₃ whereas the lowest COP (1.89) is calculated for the synthetic refrigerant R404A. Refrigerants R134a and R290 have respectively higher COPs 1.97 and 2.0 at 40 °C of condensation temperature. The COP values are located between those of NH₃ and R404A. In addition, R134a and R404A are found to have same COP (2.12) when the condensation temperature is about 35 °C.

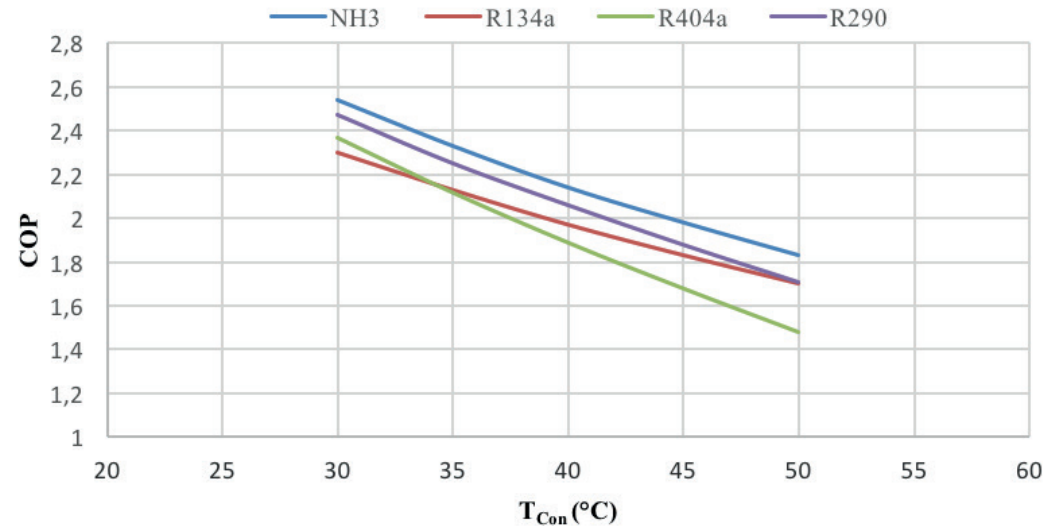


Figure 4: Effect of condensation temperature on COP

Effect of the evaporation capacity (Q_{Evap}) on the mass flow rate

The effect of evaporation capacity is also studied. As expected, increasing the refrigeration capacity raises accordingly the mass flow rate of the refrigerant. In Table 3, it is observed that increasing the refrigeration capacity from 2250W to 7250W results in an increase in mass flow rate from 0.36 to 0.37 kg/s for NH₃, 0.38 to 0.42 kg/s for R290, 0.4 to 0.47 kg/s for R134a and 0.44 to 0.51 kg/s for R404A cases. For the chosen refrigeration capacity of 5250 W the use of R404A requires the highest mass flow rate (0.48 kg/s) whereas using NH₃ requires the lowest mass flow rate (0.368 kg/s) due to its high latent heat of vaporization.

Table 3. Required mass flow rates of the refrigerants for different refrigeration capacities

Q_{Evap} (W)	$\dot{m}_{(\text{kg/s})}$			
	NH_3	R134a	R404a	R290
2250	0.365	0.40	0.44	0.38
3250	0.366	0.42	0.45	0.39
4250	0.367	0.43	0.47	0.39
5250	0.368	0.44	0.48	0.40
6250	0.369	0.45	0.50	0.41
7250	0.370	0.47	0.51	0.42

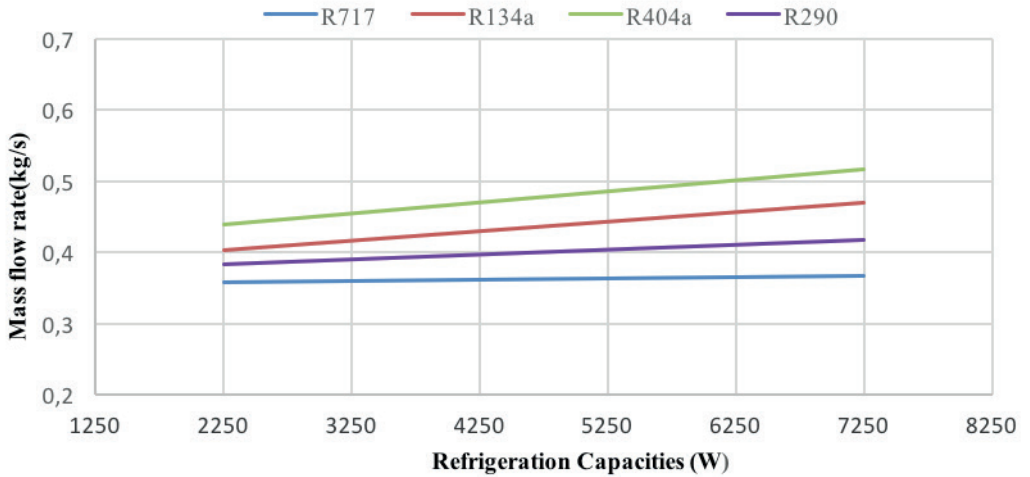


Figure 5: Required mass flow rates of the refrigerants for different refrigeration capacity.

Effect of the refrigerants to the environment

In this part of the study, the effect of using different refrigerants on the system performance and the environment has been investigated. The calculated COP values of the flash-system, GWPs of the studied refrigerants and refrigerant charge requirements are given in Table 4. In addition, GWPs of refrigerants have been examined for the leakage of the refrigerant to the atmosphere. Charge amount of NH_3 is assumed to be reference value, 1 kg, for evaporation

capacity (Q_{Evap}) of 5250 W. Accordingly, mass flow rates with other refrigerants; R290, R134a and R404A are calculated to compute the charged refrigerant amount of the flash system.

The lowest GWP is calculated for NH₃ whereas the highest GWP is calculated for the synthetic refrigerant R404A. NH₃ has total GWP value of 0 and R404A has 4944. In addition, R134a has GWP of 1559, R290 has the negligible value of GWP. As a result, it is found that the flash system of NH₃ results in the highest COP value and the best environmental performance as compared to other refrigerants. It is also observed that the COP of R404A is the lowest compared to other refrigerants, while that of NH₃ is better compared to natural refrigerant R290. As can be noted, the difference of COP between R290 and R134a can be negligible.

Table 4. Charge requirements, GWPs of the used refrigerants and COPs of the flash-system

Refrigerants	NH ₃	R290	R134a	R404a
Refrigerant charge (kg)	$m_{\text{NH}_3}=1$	$m_{\text{R290}}=1.086$	$m_{\text{R134a}}=1.195$	$m_{\text{R404a}}=1.308$
GWP	$\text{GWP}_{\text{NH}_3}=0$	$\text{GWP}_{\text{R290}}=3$	$\text{GWP}_{\text{R134a}}=1300$	$\text{GWP}_{\text{R404a}}=3780$
Total GWP	$\text{GWP}=0$	$\text{GWP}=3,27$	$\text{GWP}=1559$	$\text{GWP}=4944$
COP	1.83	1.71	1.75	1.52

4. Conclusions

In this study, the performance of the selected refrigerants, NH₃, R290, R134a and R404A, are evaluated in a flash-refrigeration system with respect to energy efficiency and environmental considerations. For the studied system, the natural refrigerant NH₃ is resulted in the highest COP value and the best environmentally friendly performance as compared to other refrigerants. It is also found that the COP of R404A is lowest. While COP values of R290 and R134a are similar, the GWP values of them are highly different. The difference between the R134a and the R290 is calculated to be 1297.

Influences of various evaporation temperatures, TL, condensation temperatures, TH and intermediate pressure, Pint, on the system COP with different refrigerants were calculated. From the results obtained, it can be claimed that:

- The COP values decrease with decreasing evaporation temperature for all refrigerant cases. Moreover, the performance of the system decreases with increasing the condensation temperature. While keeping evaporation temperature constant at 40 °C, the highest COP is obtained by NH₃ and that of the lowest found for R134a.

- Various cooling capacities have been also examined and the lowest refrigerant requirement is calculated for NH₃ and highest for R404A. It is also found that the needed total refrigerant amount is found less for natural ones.
- NH₃ seems the best candidate due to having highest COP and lowest environmental trace however it can be utilized only for evaporation temperatures higher than -25 °C.
- The second natural refrigerant option R290 can be utilized at very low evaporation temperatures, higher than -35 °C, with high COP performances. In addition, it has negligible environmental impacts concerning GWP and ODP parameters.
- R404A is found to be the worst option due to resulting in the lowest COP performance and the highest GWP. However, for the evaporation temperatures of less than -35 °C, it is the single solution.
- The second natural refrigerant option, R290, can be utilized at very low evaporation temperatures, higher than -35 °C, with high COP performances. In addition, it has negligible environmental impacts concerning GWP and ODP parameters.

Consequently, it is observed that there is not an ideal refrigerant which works in a wide range of evaporation temperatures and satisfies all efficiency and environmental requirements. However, natural refrigerants can be utilized with high efficiencies at moderate evaporation temperature applications.

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