Energy Efficient Plant Design Approaches: Case Study of the Sample Building of the Energy Efficiency Training Facilities

Idil Kanter Otcu

Abstract**—**Nowadays, due to the growing problems of energy supply and the drastic reduction of natural non-renewable resources, the development of new applications in the energy sector and steps towards greater efficiency in energy consumption are required. Since buildings account for a large share of energy consumption, increasing the structural density of buildings causes an increase in energy consumption. This increase in energy consumption means that energy efficiency approaches to building design and the integration of new systems using emerging technologies become necessary in order to curb this consumption. As new systems for productive usage of generated energy are developed, buildings that require less energy to operate, with rational use of resources, need to be developed. One solution for reducing the energy requirements of buildings is through landscape planning, design and application. Requirements such as heating, cooling and lighting can be met with lower energy consumption through planting design, which can help to achieve more efficient and rational use of resources. Within this context, rather than a planting design which considers only the ecological and aesthetic features of plants, these considerations should also extend to spatial organization whereby the relationship between the site and open spaces in the context of climatic elements and planting designs are taken into account. In this way, the planting design can serve an additional purpose. In this study, a landscape design which takes into consideration location, local climate morphology and solar angle will be illustrated on a sample building project.

Keywords**—**Energy efficiency, landscape design, plant design, xeriscape landscape.

I. Introduction

ENERGY is the most important input for economic and social development, and hence it has been a critical factor in both the developing and developed world since the Industrial Revolution. Due to the ever increasing demands for energy over the industrialization period, rapid consumption of those energy resources that have been the most economical and readily available has occurred, with the primary resources being non-renewable natural energy resources such as petrol, gas, and coal, etc. This heavy use of natural resources has led to ecological problems and changes which are now being felt on a global scale, meaning that the problem of energy supply and demand can no longer be considered on a local scale [8]. These changes have led international environmental organizations and local authorities to begin jointly considering the production and consumption of energy not only from an economic perspective, but also from an ecological one [1].

Idil Kanter Otcu is with the Department of Landscape Architecture, Ankara University, Ankara, Turkey (e-mail: idilkanter@gmail.com).

The most important studies into the production of clean energy are those which focus on the development of new technologies (wind turbines, photovoltaic panels, etc.) in order to use renewable energy (sun, wind, etc.) resources. However, due to high installation costs, limited production capacities and difficulty in the storage of the energy produced, production systems for these clean energy resources are not currently commonly used. The problems encountered during the production of clean energy shows that considering the consumption of the energy is as important as its production [19].

Energy consumption increases with urbanization, settlement and modernization of living conditions. Increases in energy consumption raise the supply price of energy. This situation makes it essential to find solutions that will reduce the need for energy, and to design highly efficient appliances. Highly efficient designs are now the preference for almost all equipment from household appliances to cars and are becoming an integral part of our lives. Today, changes in living standards as part of economic concerns and ecological awareness are also affecting the selection of houses. Housing projects which utilize sun and wind energy and take advantage of climatic conditions within the region have gained in prominence and value.

For greenhouse designs it is also important to plan vegetal arrangements so as to minimize energy consumption and enable the remaining energy to be used efficiently [13]. The purpose of this study is to create a proper vegetal design model for a sample building project by considering the selection of plant species, composition of the plants, ecological adaption, isolation, the building-plant relationship, climatic components and the basic properties that the buildings have. In the study, effective energy design strategies have been defined by evaluating approaches from different professional disciplines within the same area. Within the scope of the study, some examples of prior studies have been evaluated with regard to their application to efficient energy design strategies by considering climatic conditions, seasonal changes, properties of the field and its neighborhood, and position of the location.

II. Energy Efficient Design Strategies

The use of green buildings is increasing on a daily basis, and it is important to note that their application should be considered from a different perspective to that of traditional building designs [12].

In energy efficient building designs, the primary objective and aims should be to ascertain at the beginning of the project what materials are to be used in the building, the energy resources and potentials related to the area, the regional climate and microclimate, the solar access and insolation status of the building location, as well as the available wind power. These should be determined by means of analyses carried out in the region [10]. The objective of such analyses is to determine an appropriate design to achieve effective utilization of energy resources and facilitate the minimization of energy consumption. Energy efficient designs for the structure or its vicinity can only be achieved through energy efficient design strategies that have been produced subsequent to the analysis and evaluation work carried out in the area.

Energy efficient design strategies should be applied on a building with an integrated perspective throughout the process so that they can be efficient in the subject structure and that the desired outcome can be achieved. In this regard, the application of energy efficient plant designs to the vicinity of a structure originally designed with energy efficiency in mind facilitates a more productive outcome compared to energy efficient plant designs applied to a standard or traditional building structure [8].

Energy efficient plant designs in the vicinity of a structure are created with consideration given to the topographic and climatologic structure of and seasonal changes in the area of application, with particular attention to the efficient utilization of solar and wind power [10]. In this study, plant design approaches that aim to achieve effective utilization of solar and wind power and minimize use of water are examined.

A. Solar Power in Plant Design

Insolation status of a structure can yield electrical power for indoor use by means of systems integrated into the structure. However, methods for efficient utilization of solar power must not be limited to these systems only. Plant designs that support effective utilization of solar power can reduce the amount of energy consumed inside the structure to provide thermal comfort (heating and cooling) by approximately 25% [5]. It is therefore important to carry out a rational design of the plant material to be placed in the vicinity of a structure with consideration given to the seasonal variables.

Plants arranged with a view to solar angle and insolation status of the building during winter months reduce consumption of energy for heating purposes [4]. In this regard, the most important design approach to be applied in solar power efficient plant designs is to place deciduous trees near the façade of the building that has the most insolation, in order to provide the building with more sunshine when required, as can be seen in Fig. 1.

The amount of energy consumed for cooling indoors in the summer months is more than is used for warming indoors in the winter months [4]. It is possible to reduce indoor temperatures by up to 11°C by means of shading the structure with trees which have wide leaves, and with bushes, as shown in Fig. 1. Such natural solutions, which have been developed in order to keep indoors cool during hot summer days instead of using appliances such as air conditioners and fans that consume electrical energy, are an example of the design approaches that should be put into practice today as the entire world faces an energy supply crisis.

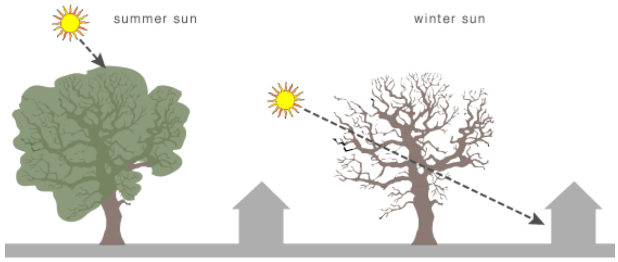

Fig. 1 Building insolation status in summer and winter seasons with energy efficiency plant design approach [14]

Vertical and roof gardens are another example of energy efficient plant designs for structures. Vertical garden (planting on the façade surface) and roof garden designs prevent the transfer of solar energy from the structures façade or roof to the inside of the building in the form of heat. Vertical garden applications carried out in mild climates reduce cooling expenses for the building by 43%, especially in the summer months, thereby playing a significant role in minimizing energy consumption [11].

B. Energy Efficiency Plant Design with Wind Power

Energy efficient plant arrangements that support the productive use of energy and dominate a structure's energy consumption must be designed with consideration given to wind prevalence and strength in the application area. The purpose is to minimize the effect of cold winter winds on the structure by correctly positioning the plant materials, and to reduce the energy consumption for indoor cooling in summer months by allowing in light summer breezes, as shown in Fig. 2 [9].

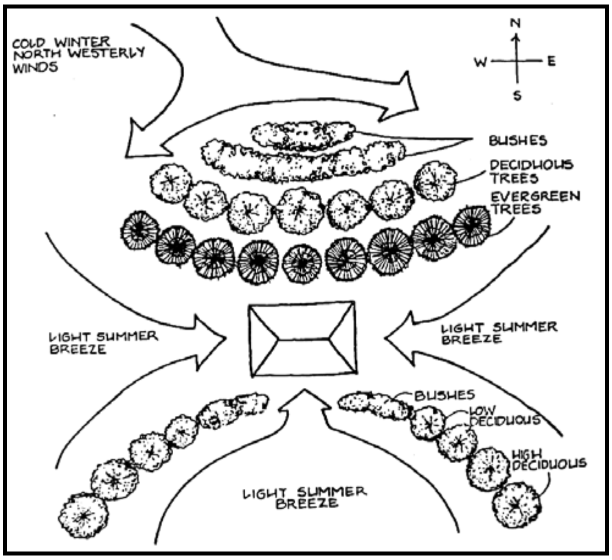

Fig. 2 The energy efficient plant design sample [9]

Vertical gardens (planting on façade surface) prevent direct contact between cold winter winds and the façade surface. This helps keep indoors warmer while consuming less energy to do so. In this regard, vertical gardens are not only a feature for aesthetics but also a system with functional characteristics.

C. Efficient Use of Water in Plant Design

Another issue as critical as energy supply nowadays, is the rapidly diminishing amount of utility water available, which causes an increase in the amount of energy consumed for supplying water. Accordingly, it is important to identify and use plant types that naturally consume less water (Xeriscape plant types) within the landscape design.

Fig. 3 Xeriscape landscape execution sample (Longmort-Colorado) [16]

Another area of study regarding minimizing water consumption is rainwater harvesting systems, as shown in Fig. 4. It is possible for rain water storage systems to be set up in gardens, especially in regions of substantial rainfall, in order to collect the rainwater falling on roofs and façade surfaces for reuse in garden watering.

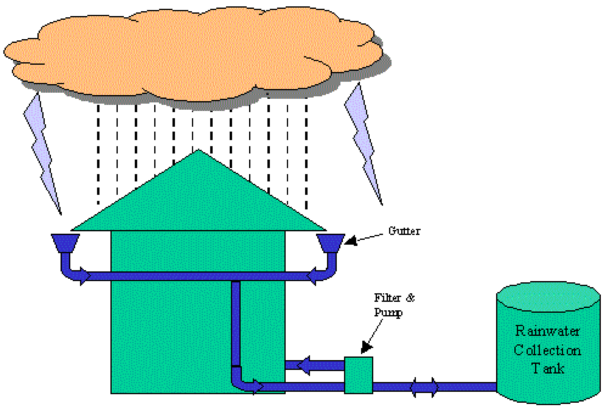

Fig. 4 Rainwater Harvesting System [17]

In this respect, recycling of rainwater reduces the need for fresh water and minimizes the amount of energy consumed in the process of obtaining fresh water. From this perspective, rainwater harvesting systems, which are developed on a domestic basis, can be considered as one of the economic improvement strategies, although they can appear to be an individual and small-scale undertaking.

III. Research Method

In light of the examined energy efficient design strategies discussed above, samples of applicable designs will now be demonstrated. A case study will be presented for the area at and around the Sample Building of the Energy Efficiency Training Facilities owned by the General Directorate of Renewable Energy. This Directorate is affiliated with the Ministry of Energy and Natural Resources of the Republic of Turkey, and is located on Eskişehir Road in Ankara. Accordingly, the review of domestic and international studies made on the efficient use of energy and determination of required approaches constitutes the first phase of this study. The method used for this study is to apply the approaches that were identified above to the sample building and be assessed based on the visual data, examinations, individual discussions and sampling arising from an ecological study.

IV. Research Findings

The Sample Building of the Energy Efficiency Training Facilities, which has been selected as the model building in this study, was built in 2006 with the purpose of developing public awareness, providing training and setting examples for energy efficient design approaches. These approaches would use systems and application techniques that make use of the energy resources in the vicinity of the structure, allow it to produce its own energy and minimize consumption of energy inside, as shown in Fig. 5 [6].

Fig. 5 Location display of Energy Efficiency Training Facility Sample Building (Ankara-Turkey) [18]

The two-story building with a total area of 275 m^2 incorporates state-of-the-art heat insulation techniques, solar energy systems, geothermal energy systems (ground-originated heat pumps), fiber-optic lighting systems, daylight control systems and composite walls for heating/cooling, etc. [2]. This example of a green building is composed of many designs put together into a model building which can be studied and which can provide results on what can be achieved in energy efficient plant design work.

The northern, southern, eastern and western façades of the building are open by location. A coating system has been applied on the northern, eastern and western façades for heat insulation purposes. The surface of the southern façade is covered with a glass-case constructed from low radiation coated heat control glass (*). About one meter inside this glass-case is the trombe wall. The trombe wall facilitates the trapping of solar heat through the glass-case and transferring the trapped heat to a system in the wall.

Thus, the system makes it possible to warm up the building better with a lot less energy consumed in the winter months.

The façades of the sample building are shown in Figs. 6 and 7.

Fig. 6 (a) The appearance of the northern façade of the sample building

Fig. 6 (b) The appearance of the southern façade of the sample building

Fig. 7 (a) The appearance of the eastern façade of the sample building

*Low radiation coated heat control glasses reduces heat loss from the building to outside by reflecting back inside the heat radiated from sources of heat such as radiators, stoves inside the building.

Fig. 7 (b) The appearance of the western façade of the sample building

The research carried out has revealed that the plant material around the building is composed of the plant types that existed in the region during the structural projection phase. No energy efficiency related arrangements have been made in the vicinity of the sample building in this regard.

A. Analysis towards Energy Efficient Plant Design for the Building Close Environment

Plant arrangements to be made in the vicinity of the structure to facilitate productive use of energy inside the structure must be designed taking into account the meteorological and climatic data of the application region. In this respect, for the plant arrangement to be designed for the vicinity of the Sample Building of the Energy Efficiency Training Facilities, the climate type of the province of Ankara must be reviewed and temperature, insolation and rain data must be determined, as presented in Table I.

B. Energy Efficient Plant Design Samples for the Building and the Building Close Environment

In the energy efficient plant design which is to be carried out in the vicinity of the sample building examined in this study, the primary aim is to determine the types of plants that are suitable for the region with regard to the climatic data. Determination of suitable plant types must be based on their ability to thrive in the type of climate encountered in this region. However, energy efficient plant designs should also aim to mitigate the effect of the extreme climatic values on the structure during the winter and summer months.

Once the plant types have been determined, with due consideration given to the lowest and highest climatic values for the province of Ankara, as given in Table I, these plants should be positioned with the purpose of facilitating lower levels of insolation and thus less warmth for the building in the summer months, and more insolation and thus more warmth in the winter months. Plant types with denser leaves like *Acer platanoides*, *Aesculus hippocastanum* and *Tilia cordata* are most successfully used in energy efficient plant designs applied in regions with a terrestrial climate due to their ability to filter out solar beams by 95% and solar heat by 75%. An additional advantage is that they defoliate in winter months and hence allow the transmission of solar beams inside. Tall trees are preferred as they will be efficient in shading each floor of the building.

TABLE I
CLIMATE OF THE ANKARA CITY (1954- 2013) [3]

Ankara	Jnr	Feb	Mar	Apr	May	Jun	July	Agu	Sep	Oct	Now	Dec
The Average Values (1954-2013)												
AVG Temp (^{0}C)	0,4	1,9	6,1	11,3	16,2	20,2	23,6	23,3	18,7	13,1	7	*2,6*
AVG MAx Temp (^{0}C)	4,4	6,5	11,7	17,2	22,3	26,7	30,2	30,2	25,9	19,9	12,9	6,6
AVG Min Temp (^{0}C)	-3	-2,2	1	5,6	9,7	13,1	16	16	11,7	7,3	2,5	-0,6
AVG DUR of SI (hour)	2,5	3,5	5,2	6,3	6,4	10,2	11,4	11	9,2	6,5	4,4	2,3
AVG NUM of RD	12,2	11	10,9	11,9	12,5	6,6	3,7	2,8	3,9	6,8	8,5	11,8
AVG of MLY TTL P (kg/m^2)	42,2	37	38,8	47,7	49,7	35	14,5	10,5	19,2	29,4	32,6	45,4
The lowest and the highest values for many years (1954-2013)												
HIGHEST TEMP	17	20	26	31	33	37	41	40	36	32	24	20
LOWEST TEMP	-21,4	-21,5	-19,2	-6,7	-1,6	3,8	4,5	6,3	2,5	-4,1	-10,5	-17,2

AVG= average, TEMP = Temperature, MAX = maximum, MIN = minimum, DUR = duration, SI = solar insolation, NUM = number, RD = rainy days, MLY = monthly, TTL = total, P = precipitation.

An energy efficient design approach could also be used to protect the northern façade from cold winter winds. With the plant designs to be applied around the building's northern façade, it is possible by preventing direct contact between the cold winter winds and the building to keep the indoor temperature stable with lower consumption of energy. From this perspective, a group of bushes (*Buxus sempervirens* L., *Berberis thunbergii* L.) is to be positioned at the northern part of the building's vicinity. Planting these bushes in the form of an arc will be efficient in stopping strong winds. Types of low deciduous trees such as *Rhus coriaria* L. and *Viburnum lantana* L. positioned right behind the group of bushes in an arc form will help mitigate the strength of cold winter winds. Types of evergreen plants like *Elaeagnus angustifolia* L., *Pinus sylvestris* L. and *Picea orientalis* L. positioned closest to the building behind the low deciduous trees, again in an arc formation, play a significant role in energy efficiency by minimizing contact between the cold winter winds and the building. In this kind of energy efficient plant arrangement, it is preferable to compose the design with three different layers in order to achieve suitable positioning for blocking severe winter winds [15], as shown in Fig. 8.

Fig. 8 (a) The existing plants

Fig. 8 (b) The sample plant design which blocks cold winter winds

Vertical garden designs applied on the structure's façade can be given as another example of energy efficient plant design. Today, vertical gardens are not only preferred for aesthetic purposes, but are also highly significant in terms of functionality with their characteristics of minimizing the sudden climatic changes indoors due to building surface exposure to cold winter winds in winter months and solar beams in summer months [7]. With the vertical garden design to be applied on the northern façade of the sample building being examined in this study, it will be possible to block cold winter winds, as shown in Fig. 9.

Fig. 9 (a) The bare façade

Fig. 9 (b) The vertical garden sample

Taking into account the climatic data of the region, bushes positioned at the bottom of the walls are able to mitigate strength of snowfall towards the wall and are capable of holding snow. Additionally, as a result of positioning durable types of terrestrial climate plants like *Parthenocissus quinquefolia* and *Celastrus scandens* with climbing characteristics right in front of the building façades, it will be possible to create a warm air pocket between the building façade and the plants and hence minimize temperature drops inside.

V. Conclusion

Highly efficient mechanical and electronic systems are very important for the design of energy efficient buildings. However, as well as the systems that aim to use energy efficiently, designs that aim to use renewable energy resources efficiently also have to be integrated into these projects. In this respect, highly efficient plant designs that can be planted in the vicinity of the building become important.

It is possible to develop plant design approaches that can ensure the efficient use of natural resources such as sun and wind, providing that the climatic conditions of the region are considered. In this way, this study has developed energy efficient planting designs for the sample building used in the case study, whilst considering climatic conditions, average precipitation values, insolation periods and wind potential.

Although studies about the properties of plants in relation to energy efficiency are being newly applied in cities where there is dense housing, many approaches based on the judicious use of plants and water have been applied since 2000 BC. Some of these early methods for addressing energy efficiency have included the usage of plants grown on fences as wind breaks, covering the walls of buildings with climbing plants to prevent heat loss and placing tall broad-leaved trees in the vicinity of buildings in order to provide shade. Analyzing the examples of these methods which have been used since ancient times supports the intelligent use of natural resources. Making these approaches generally applicable to today's buildings is an important area of study in relation to energy efficiency.

References

[1] "Land-use Planning and Renewable Energy in Cornwall", Cornwall Cpunty Council, Department of Trade and Industry, Truro, England, (1996).
[2] "Enerji Verimliliği Eğitim Tesisi Örnek Bina Tanıtım Broşürü", Republic of Turkey Ministry of Energy and Natural Resources, Ankara, Turkey, (2014).
[3] "Official Statistics Data of Ankara Province", Republic of Turkey Ministry of Water Affairs and Forestry, General Directorate of Meteorology, http://www.dmi.gov.tr/veridegerlendirme/il-ve-ilceler-istatistik.aspx, (2014), Accessed date: 11.02.2015.
[4] "Cooling Your Home Naturally", http://www.nrel.gov/docs/legosti/old/15771.pdf, U. S. Department of Energy (DOE) – The National Renewable Energy Laboraory (NREL), (1994), Accessed date: 19.07.2015.
[5] "Landscaping for Energy Efficiency", http://www1.eere.energy.gov/library/pdfs/16632.pdf, U. S. Department of Energy (DOE) – The National Renewable Energy Laboraory (NREL), (1995), Accessed date: 20.07.2015.
[6] Çayırlı Y, Bireysel görüşme notları. Republic of Turkey Ministry of Energy and Natural Resources, General Directorate of Renewable Energy, Ankara, Turkey, (2014).
[7] Kanter İ., Oğuz D., Elinç Z. K., "Dikey Bahçelerin Bina Cephelerinde Kullanıldığında Sağladığı Isı Tasarrufu; İzmir Alsancak'ta bir Bina Örneği", Intelligent and Green Building Conference and Exhibition Proceedings, S:182-190, Gazi University, Faculty of Architecture, Ankara, Turkey, (2013).
[8] Karaca M., Varol Ç., "Konut Alanlarında Enerji Etkinliği: Toplu Konut İdaresi Başkanlığı (TOKİ) Toplu Konut Projeleri Üzerine Eleştirel Bir Değerlendirme", METU JFA, 29:2, p: 127-141, Ankara, Turkey, (2012).
[9] Moffat A. S., Schiler M., "Energy efficient and Environmental Landscaping", Appopriate Solutions Press, The United States of America, (1993).
[10] Tuğaç Ç. G., "Enerji etkn Planlama Yaklaşımının Kentlerin Ekolojik Planlaması ve Tasarımı Süreçlerine Etkisi- Güney Ankara Ahiboz Koridoru Örneği", Master Tezi, Şehir ve Bölge Planlama Anabilim Dalı, Gazi Üniversitesi, Ankara, Turkey, (2003).
[11] Perini, K., Ottele, M., Haas, E. M. and R. Ralteri, "Greening the Building Envelope", Façade greening and Living Wall Systems, Open Journal of Ecology, Vol.1, No.1, 1-8, (2011).
[12] Roaf S., Fuentes M., Thomas-Rees S., "Ecohouse 2: A Design Guide", Elsevier, Italy, (2003).
[13] Robinette G. O., "Landscape Planning for Energy Conservation", Van Nostrand Reinhold Company, New York, (1983).
[14] Building insolation status in summer and winter seasons with energy efficiency plant design approach, http://www.greenspec.co.uk/building-design/energy efficient-windows/, Accessed date: 10.08.2015.
[15] Swackhamer E., Sellmer J., "Using Trees and Shrubs for Privacy and Wind Screening", Department of Horticulture, The Consumer Horticulture Center, The Pennsylvania State University, (2012).
[16] Xseriscape Landscape Execution Sample, http://www.landscapingnetwork.com/Xeriscape-landscaping/, Accessed date: 15.08.2015.
[17] Rainwater Harvesting System, http://www.lakotawatercompany.com/HowItWorks.htm, Accessed date: 20.02.2016.
[18] Location Display of Energy Efficiency Training Facility The Sample Building, http://earth.google.com, Accessed date: 19.02.2015.