

Case Studies on the Impacts of Climate Change on Historical Buildings in Northern Cyprus

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ABSTRACT

The changing in climatic conditions is one of the most significant issues in the twenty-first century. The literature suggests various approaches for the understanding of the harmful influences of climate change. Climate change is caused by increases in atmospheric greenhouse gases, deforestation, altering watercourses and human actions with tragic effect on the environment has turned into certainty, as that the procedure may not be over in a short period or medium period. Climate observations showed that climate change occurrence had unfavorable impacts on society and mostly on built environment. The most vulnerable buildings are the historical buildings. The impact of climate change on historical buildings should be studied very carefully to determine the meteorological parameters and changes which are the most critical for the protection of the cultural heritage. Prediction of the effects of climate change on built cultural heritage for the next 100 years is necessary to take every step to protect the historical buildings that are likely to be worst affected by climate change effects. Against this background, this paper reviews the physical and chemical deteriorations of historical buildings and changing energy consumption of historic buildings. The research exposed the risk to lose cultural heritage and rising energy demand in the Northern part of Cyprus as a case study. Structural engineers and architects should consider the dominant forces of climate change to protect the historical buildings but also to construct sustainable, feasible and durable buildings for future projects.

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1. Introduction

Climate is the statistics of weather conditions in the extended period. It differs from weather, by describing long-term conditions in a region. It provides functional survival needs like air, temperature, water, and wind during the lifespan of living things on the planet. Therefore, any changes in climate will have a direct and indirect effect on the health of people. It is very

well known that global warming and hence the change in the climate is the consequence of human activities. The industrial revolution marked as the turning point of climate change. There is an incremental increase in greenhouse gas emissions to the atmosphere due to the industrial activities. The construction industry is one of the most important sector which releases vast amount of carbon dioxide (CO₂) emissions into the atmosphere and also generates a very significant amount of waste which is

difficult to deal with. According to IEA 2017, Buildings and construction account for more than 35% of global final energy use and nearly 40% of energy-related CO₂ emissions. Therefore, it is confirmed that the construction industry has a significant impact on climate change.

On the other hand, the changes in climate change have a detrimental impact on the buildings as well. The researchers have always been focusing on the damaging effects of materials used or the greenhouse gases (GHG) emissions caused by the construction industry. However, a little attention was paid on the fact that global warming and hence climate change also influence the quality, durability and safety of the buildings and hence the materials used. The CO₂ release from the buildings is mostly happening due to the fossil fuels used for providing heating and cooling purposes. Generally, fossil fuels are the most widely preferred sources to achieve primary world energy. In 2016, fossil fuel usage provided 80% of world energy (World Energy, 2019). Therefore, CO₂ and methane concentrations are increased as a result of the high amount of fossil fuel usage. These atmospheric changes with human-induced natural influences have changed the climate. Higher temperature rates, hot extremes, heat waves, heavy precipitation and decreases in snow thickness are some significant effects in climatic changing conditions. In brief, based on the current observations made by scientist it is clear those human activities have a detrimental impact on environmental health, and this change in environment also has a detrimental impact on the human health. On top of that, it is true to say that any negative impact on the environment would directly have an influence on every living and non-living things on this planet. Therefore, it can be stated that climate change which have been initiated by the human activities currently affecting their health but also everything else on this world. The construction industry was also initiated by the human beings to provide them shelters and since then not every progress was kept under control to observe any negative impact of all these developments would have on the environment or human health. For example, a high amount of nonrenewable energy use is at least one aspect which was supposed to be controlled in order not to increase any GHG emissions into the atmosphere. All the buildings are exposed to the environment, and hence they may be influenced negatively. Therefore, it is important to observe the contribution of historical buildings into energy consumption and what has influenced them till today by means of detrimental changes in the environment. As it was also mentioned by Ak, 2016; climate change may cause deteriorations on especially stone-based construction materials used in historical buildings. Climate change may lead to reduction of the material durability and may cause static problems for the building. The changes in temperature may have negative impact on the construction materials used in historical buildings; as of changes of the colours of stones by time. The main causes of the deterioration may be listed as: significant changes in air temperature, thermal expansions, solar and atmospheric effects, water and humidity, wind and most importantly deteriorations due to air pollution. All of these may not only cause deformation or deterioration of historical buildings but they may also cause disappearance of partial or whole structure within a period of time.

It is important to investigate and analyse the impacts of climate change on historical buildings since only very little known if and how climate change influences the historical buildings which are our cultural heritage. The impact of climate change on historical buildings should be studied very carefully in order to determine the meteorological parameters and changes which are the most critical for the protection of the cultural heritage. Prediction of the effects of climate change on built cultural heritage for the next 100 years is necessary in order to take every step to protect especially the historical buildings that are likely to be worst affected by climate change effects. Therefore, the main scope of this research is to investigate the impact of climate change on historical buildings and incremental growth of energy consumption in buildings. Particular emphasis is provided on the potential impacts of climate change on historical and monumental buildings by investigating different features of the buildings in a discussion. Energy consumption performances of the buildings are also discussed in this paper. A few recommendations will be made to represent possible alternative solutions to minimize energy consumption.

2. Materials and Methodology

2.1. Cyprus as a Case Study

Cyprus is the third largest island in the Mediterranean Sea. It is situated just in the middle of crossroads of three continents: Europe, Asia and Africa. A historical island like Cyprus owns the chance of having so many different cultural impacts on ancient buildings. This small island due to its strategic geographic positions has been visited, coveted, conquered and colonized many times during its 10,000- year history. It is pretty easy to observe the traces of each nation visited the island during the history including seeing Greeks, Romans, Byzantines, Lusignans, Genoese, Venetians, Ottomans, British, and Turks. The historical places and buildings exist in Cyprus provide the opportunity to observe the traces of each nation visited the island during the history.

Historic buildings are the national cultural value of each country, which is a bridge from past to present with extensions to the future (Tavukçuoğlu, 2000). They have undertaken a public mission for giving opinions to the next generations regarding the national heritage. In order to narrow the area of study, the historical buildings investigated are only chosen from Northern part of Cyprus.

2.2. Methodology

This research was undertaken according to personal observations regarding to the current conditions of historical buildings in Northern Cyprus. Specific, measurable parameters are taken into accounts which are temperature, rainfall, wind velocity and direction, the rate of evaporation and relative humidity. These parameters will be mentioned and discussed within the context of the study. In order to understand, investigate and able to

compare and analyses the past, present and future of the historical buildings and evaluate how much they have been influenced by climate change. This review paper answers two fundamental questions; which are:

- What are the impacts of climate change on historical and monumental buildings?
- How will energy demand be affected by climate change?

In order to compare and figure out the development of architectural features of the ancient buildings in the chosen area of the study; all available literature was also reviewed.

3. Findings and Discussions

3.1. Historical and Monumental Buildings

The observations made in the research study were supported with the information available in the literature. There are a few and limited data available on the structural information of the historical buildings so quantifying the findings is pretty difficult by means of evaluating the level of deterioration happens in the last 10 to 100 years. In order to quantify the observations made, this study needs to be supported with the old data regarding to the deteriorations happened on the historical buildings. This paper was undertaken with the scope and aim to act as an initial work which encourages future works to be done in this area hence we can really predict what could be happen in the coming 100 years to the historical buildings due to the effect of climate change and hence may be prevented to be happening.

In all over the island, it was observed during the construction of almost all ancient and historical buildings natural stones were used. In general, natural stones are used as the primary raw material to construct historical buildings. One of the main disadvantages of using natural stones is due to the fact that atmospheric pollutants combine with climatic factors, and they cause deteriorations in buildings depending on the type of stones. The conservation of stones is based on understanding the current situations of historical buildings. These situations include the geological characteristics identification of the existing structure, climatic conditions, impacts of air pollution and natural catastrophe. The weathering of stone occurs as a result of physical, chemical, mechanical and biological processes. Briefly, temperature effects, atmospheric effects, and living beings are mainly responsible for deteriorations of sandstone and limestone as investigated by Yıldız, 2010 and Ak, 2016.

3.1.1. Temperature Effects And Precipitation

Natural sandstone and limestone were the most commonly used construction materials for historical, cultural and monumental building types in ancient times due to their high resistance against to natural environmental conditions. Although they have high resistance, they are affected during the time cause of the world's climate change. The state of the stones changes the protection and usage status of the historic structures. The stone materials of historical buildings are affected generally by temperature variations and solar impacts. Various photos were

taken in order to show the modifications these stones gone through due to the varied climatic conditions, i.e. sharp changes in temperature. According to the Department of Meteorology of Cyprus, it is said that climate change has a severe effect on Cyprus climatic conditions. The main changes have been observed on the amount of precipitation and mostly temperature. The annual precipitation values and degree of temperature are given as below:

- ✓ The average annual Precipitation in between 1991/1992 and 2007/2008 years (17 hydro-meteorological years) was found to be 457 mm or 9% lower than normal (503 mm, period 1961-1990).
- ✓ The average annual Temperature in the period 1991-2007 is 17,7°C or 0,5°C which was 17,2°C higher than period 1961-1990.
- ✓ According to the above rate of changes, it is expected that by 2030 Precipitation will decrease by 10 - 15% and Temperature will increase by 1,0 - 1,5°C compared to the normal values of the period 1961-1990.

(Department of Meteorology, 2019)

3.1.2. Thermal Expansion

The temperature difference between day-night and seasons of the year ends with volume change such as expansion and shrinkage. It is well known that temperature difference increases with climate change in all around the world. Moreover, consistent temperature variations create the cracks and fractures on stones in consequence of the fatigue material. Different enlargement amounts of stone material are an alternative influence of temperature. It occurs as the cause of temperature differences between internal and external sides of stone materials. The global temperature increment change is shown in Figure 1.

On the other hand, thermal expansions occur not only because of temperature changes but also freezing plays another role in contraction. Since water enlarges its volume later the freezing procedure, frozen water inside cracks causes broken pieces of stones. When the same process happens progressively many times, breaking of stones will take place frequently. Freezing-thawing leads to deformation of stones at the places, where it has a significant daily and seasonal temperature differences. Architects prefer to change stones when they deform 80%, during the restoration process of monumental structures. Temperature increase with a rate of 0.01°C each year observed in Cyprus Island during the 20th century.

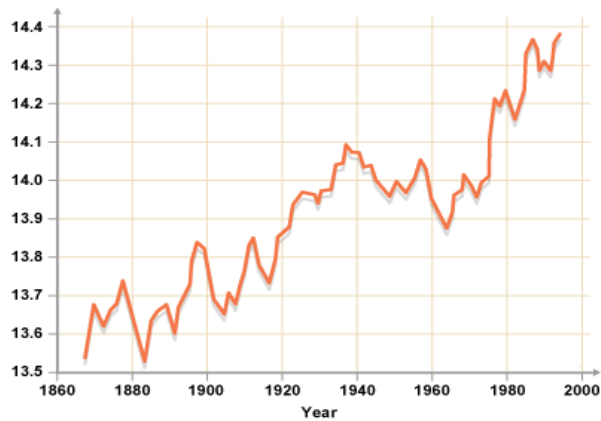


Figure 1 Global average temperature (°C) between 1860 and 2000 (BBC, 2018)

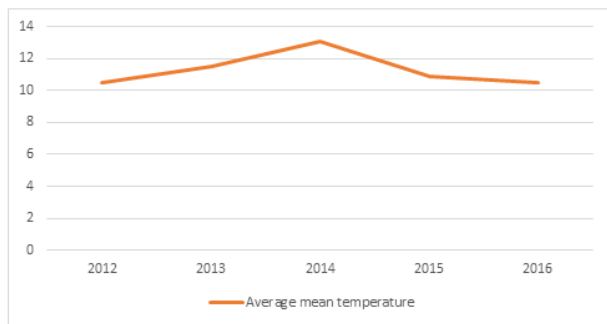


Figure 2 Average mean temperature (°C) on January 2012-2016 in North Cyprus (TRNC SPO, 2019)

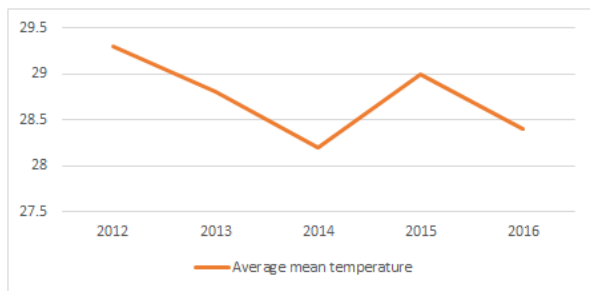


Figure 3 Average mean temperature (°C) on August 2012-2016 in North Cyprus (TRNC SPO, 2019)

3.1.3 Solar Effect

Temperature differences between day and night result in changing the colors of stones. Figure 2 and 3 shows the differences in temperature during the winter and summer seasons in Cyprus in between 2012 and 2016 years.

Temperature differences between day and night result in changing the colors of stone as in Figure 2.

Therefore, faded surfaces take a matt and pale looking in natural construction stones depending on temperature changes.

Dark spots are also observed in monumental and historical buildings as a solar effect. See Figure 4



Figure 4. Discoloration in stones of Great Inn (Büyük Han) in the Turkish Republic of Northern Cyprus (Media, 2018)

3.1.4. Atmospheric effect

Atmospheric motions and moisture are evaluated as hazardous factors towards keeping monumental buildings in safe. Although the stone substance has terrible weather condition resistance, it goes through deterioration after a while, and it sometimes destroys existing stones in monumental buildings. Massive damages on soft stones cause to particles that are brought by winds.

On the other hand, stones can experience cracks or fracturing into pieces in consequence of stresses under the effect of temperature variations, freezing-thawing, and moisture variation. Furthermore, under the effect of disturbed atmosphere organisms and water lead to chemical dissolution on stones. The dust layer increases its thickness in the course of time by generating dirty layer on stones. The classification of the type of deteriorations is in accordance with the effect of water and moisture, salts, winds and air pollution for the subtitles of atmospheric composition.

3.1.5. Water and Humidity

Humidity is known as one of the most critical deleterious determinants towards stone-made structures. Limestone dissolves under the effect of rainwater and CO₂. Furthermore, the acid rains are the threat of stones that are brought by the rainwater whose capillary rise in the building leads to undesired impacts on the material consumption. The soil layer between the earth surface and groundwater level keeps water by capillarity, which does not permit to get rid of drainage system usage. The high amount of humidity brings damages to the structure. Simultaneously, the saltactivation with the help of water and moisture also affect the building materials.

3.1.6. Wind

The transportation and installation of seed into cavities, joint point between walls and roofs with the effect of wind lead to mature trees on the neglected surfaces of historical and monumental buildings. Therefore, it helps to speed up decreasing the lifespan of the monumental buildings. Furthermore, if wind shows its negative impact with sand and sea salt; severe surface weathering will occur on the historical buildings. Water dissolved salts are transported inside the pores in the building materials, and water salts collect on the surface of stone or at the thin cracks of stone by the effect of evaporation. The presence of water-soluble salt particles in a stone-made structures leads to textural and mineralogical damages within the time. On the other hand, salt crystallization is another reason for deteriorations on monumental and historical buildings.

3.1.7. Air Pollution

Air pollution has a significant effect on stone materials. Gas and ion resolutions brought to the surface area of structures with water, rain; atmospheric motions, wind, snow, and rainfall lead to weathering on the outer surface of a stone. Chemical weathering changes the composition of stones with the help of chemical reactions like dissolution, hydrolysis, and oxidation of stone materials. Air pollution is mainly responsible for chemical weathering. Wind, relative humidity, fog, sunlight and solar radiation are well known meteorological factors that cause faded stones. The air pollution is directly proportional to the location of the place, where air pollution is the single factor on the brilliance loss of limestone.

3.1.8 Biological Activity

Biological activity has been affected by climate change in historical buildings and on cultural heritage materials. Fungal activity has adverse effects on cultural heritage. Lichens and mosses are formed in winter session due to climate and cause deteriorations on historic structures. Deterioration processes go along with biochemical transformations, which happen at specific temperatures in the development process of the organism. However, temperature, moisture, and nature of the substrate affect the development of organisms. Spores can germinate at temperatures above 0°C and moisture level of more than 70% (Leissner et al. 2015). Most fungi activity happens between 0°C and 50°C. Biological action is based on temperature and particular minimal moisture for growing. Mold growth plays another role in deteriorations of historical buildings. It expects the minimum temperature to starts for its activity. Sedlbauerisopleths system (Sedlbauer, 2001) offers simulated risks to determine the potential danger of mold growth. Mold risk index can be used to categorize their growth activity (Viitanen et al., 2007). Mold risk index;

- 0: No growing
- 1: Some growing observed together with the only microscopy
- 2: Moderate growing observed together with microscopy (coverage higher than 10%)
- 3: Some growing observed visually
- 4: Visually observed coverage by greater than 10%
- 5: Visually observed coverage by greater than 50%
- 6: Visually observed coverage 100%

Table 1 provides various pollutants and their impacts, especially on cultural materials.

Table 1 Pollutants and their impacts on cultural materials (Shaglouf et al., 2016)

| Types of Cultural Properties | Effects | Pollutants |
|------------------------------|------------------------------|---|
| Metals | Corrosion, discoloration | Acid rain, SO _x , NO _x , Cl |
| Stones | Discoloration, deterioration | Acid mist, SO _x , NO _x , Cl |
| Wooden | Deterioration, discoloration | Acid rain, SO _x , NO _x , Cl |
| Wall paintings | Peeling, discoloration | Acid mist, SO _x , NO _x , Cl |
| Glass | Cloudiness | Acid rain, SO _x , NO _x , Cl |
| Oil paintings | Ammonia | Deterioration of oils Cloudiness of varnish |

3.2. Energy Consumption

Many researchers have conducted studies regarding climate change effect on energy consumption. Generally, gas and electricity needs for the heating decrease and increase for cooling day by day in different places of the world. There is incremental growth concerning about climate change and its effect on energy usage. Heating, air conditioning, and ventilation energy demand cover 34.8% of building energy consumption in the United States (Jiang et al. 2017). Moreover, humidity has an essential impact on electric energy consumption. When high temperature combines with high moisture, it directly raises the energy requirement for climate control. For instance, high amount of air conditioning usage throughout hot and humid summer sessions and the usage of electric energy and gas for heating purpose in winter session months, residential and commercial buildings in Florida counted 23.7% and 28.6% of increasing energy need in 2013 according to U.S Energy Information Administration in the year of 2015. Intergovernmental panel on climate change (IPCC) estimations show increment in global average face temperature within varied forms. Watkins et al. (2002) indicated that buildings would be warmer so an extra cooling energy demand will be required. Therefore, sustainable low energy buildings are alternative design models to provide thermal comfort under the

effect of warmer summer sessions. Wang et al. (2010) found the climate change effect on residential buildings by using five different regional climates in Australia with regards to heating and cooling energy requirements. Therefore, energy efficient residential buildings need less energy change requirement cause of climate change according to this study. There are intensive researches on the impact of climate change on buildings all over the world. Humidity and average global temperature will increase according to findings, so it will directly affect building energy consumption exclusively in subtropical climatic areas. Moreover, the impacts on energy usage are based on climatic zones, building types and area (city, rural) of the buildings as well. Architects and engineers play an essential role in designing and constructing energy-efficient buildings. (Hurlimann et al., 2018)

The logic of building energy demand modeling is by a prediction of future demand or increasing energy efficiency. Generally, simulations are performed with BEND (Building Energy Demand) model that is a platform for analyzing building benefits from energy plus.

Peak demand is a critical point for developed countries. In many studies, energy consumption is associated with annual or monthly heating degree-days (HDD) and cooling degree days (CDD) in the same period (Chaturvedi et al., 2013; Kaufmann et al., 2013). BEND is a part of the model from the Platform for Regional Integrated Modeling and Analysis (PRIMA), improved by Pacific Northwest National Laboratory (Kraucunas et al., 2014). The following points are of significant importance in such analysis processes

- Detect the number of parallel climate regions for the geographical region of interest. Climate conditions are associated with calculation time as well.
- Determine the number of buildings and characteristic features of these buildings. The building's features could change in the course of time.
- Use climatic data in the convenient form for adjustment according to actual historical weather and simulate data regards to climate change estimations.
- Collect real energy consumption information for areas and prepare the sample from old time records.
- Analyze the following climatic data by using the draft model to calculate further building energy demand and peak electric energy need under the impact of estimated future climatic conditions.
- Obtain the building energy consumption profiles for the geographical area of study.

Dirks et al. (2015) studied energy spending and peak demand in buildings by thinking of a comprehensive regional perspective in the United States of America. They used the computational assessments of scenarios change for Delta Ecosystem (CASCaDE) dataset to predict future climate conditions, and then they transformed climatic information into BEND model. In CASCaDE dataset rainfall for day by day, maximal and minimal temperature from GCMs (General Circulation Models) were considered. The results are obtained for 2004, 2052 and

2089. Temperature data separated into four sessions for any year as follows.

- Spring session (Includes March, April, May)
- Summer session (Includes June, July, August)
- Autumn session (Includes September, October, November)
- Winter session (Includes December, January, February)

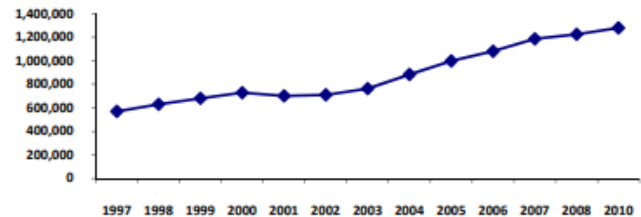


Figure 5 Electricity generation (Kwh) in 1997-2010, North Cyprus (Ozerdem and Biricik, 2011)

3.3. Energy Saving Recommendation

Energy consumption reduction is a type of challenge in building design against climate change conditions, and it needs an extra budget. Thermal achievement improvement of building by applying phase change material (PCM) is a type of technique to minimize energy consumption for future climate conditions. PCMS is added to building envelope to charge and leave energy as hidden heat in low-temperature intervals that causes incremental growth for building's thermal mass. As a summary, PCM decreases heating loads, loads of cooling, carbon emission and offers comfortable living conditions.

In North Cyprus the electricity generation is increasing very sharply in parallel to the need of energy need as shown in Figure 5. Therefore, every step should be taken to reduce the consumption of energy. The buildings consume 20-40% of the energy reserve according to current studies (Heier et al. 2015; Saffari et al. 2016). On the other hand, heating ventilation and air conditioning (HVAC) covers the %50 of the building energy (Saffari et al. 2016; Marin et al. 2017). Moreover, buildings contribute to greenhouse gas emission as the amount of 30-40% (Hussain et al. 2017; Vicente et al., 2014).

Different types of technologic innovations have been offered to reduce the building energy demand and develop thermal comfort. Isolation materials, double-glazed reversible window arrangement, heat insulating solar glass, hybrid walls with the collector and thermal power generators are kind of examples for reducing energy consumption and increasing thermal comfort. Reinforcing building envelopes together with thermal insulation is a method to decrease heat distribution from interior to exterior. This method increases energy efficiency so, reduces the amount of greenhouse gas emission. Building envelope and smart HVAC equipment are good ways to obtain a sustainable energy performance. (Soares et al., 2014) discovered that PCM increases energy yield by 10-60% according to climate region

when applying to drywall inside lightweight steel-framed buildings.

Researchers made a test to identify the energy recovery potency of PCMS in buildings under the effect of future climatic cases (Gassar et al. 2017). The experimental description is presented in the following.

- The building was an office building with three-story and an area of 1,660.73 m².
- The ratio of the window to the wall is 33% of the total wall area.
- Three types of PCM was used (BİOPCM, DUPOnergainPCm, MRUBITHRMPcM).
- The climatic zones considered in addition to humid tropical and subtropical climates.
- Three climatic zones were Seoul, Tokyo and Hong Kong.
- The further climate duration contains the years 2020, 2050 and 2080.

This study concludes that PCM together with suitable melting stage temperature into a building's envelope can save energy in the course time cooling and heating periods.

4. Observations on the Impact of Climate Change on Historical Buildings in Northern Cyprus

Several observations were made in some selected historic buildings in Northern Cyprus mainly focusing on the capital city of the island. Several photos of the selected historical buildings are provided below to demonstrate the effects of climate change on monumental buildings. As it can be easily understood from the photos taken by the authors of this paper; it is clear that increasing rate of temperature and unexpectedly increasing rate of rain falls has caused an increase the amount of humidity. The detrimental impact of this humidity was felt obviously as soon as had a look at the buildings.

Figure 6 represents Bedesten or Bedestan which is a historical building in the Selimiye quarter of North Nicosia, located directly beside the Selimiye Mosque (Figure 7). The structure has a long and complicated history spanning more than one thousand years.

In almost every single historical building (see Figure 6, 7, 8, and 9, respectively) exists in Nicosia; generally, alga and black color formation was observed on yellow which is used for the façade of the all buildings observed. In addition, as seen in the last photo of the Selimiye Mosque, it was observed that the plant was grown on the arches.



Figure 6 Bedestan



Figure 7 Selimiye Mosque



Figure 8 Sultan Mahmut II Library



Figure 9 An old house located in the center of Nicosia

5. Discussions and Conclusions

According to the observations made and available local resources, it is known that the historical buildings exist on the island were constructed mainly using stones which were accepted as the natural construction materials at the time they were used. Based on the observations made it is clear that serious deteriorations occurred on the buildings by time.

The deteriorations observed might be occurred due to the age of the structures but mostly due to the environmental conditions and factors. As it was mentioned earlier in this paper, significant and sudden changes in temperature, rainfall level, wind, and humidity are the main causes of these damages on the historical buildings. It is apparent that more is expected to be occurred in the upcoming years if no further action is taken in order to protect the historical buildings.

Overall it can be concluded that:

- The vulnerability of historical and monumental buildings in Cyprus increases with many types of deteriorations cause of climate change impact.
- Cultural heritage works have no long lifespan due to unexpected changes in climate.

- New design standards can be generated for future design models by considering the current investigations on historical and monumental buildings.
- Energy consumption will increase not only in Cyprus but in the entire world, especially for cooling purposes.
- Thermal isolation material usage in buildings can be mandatory with laws to encourage less energy consumption.
- Smart heating ventilation and air conditioning system has promise future to regulate energy consumption.
- Energy savings can be supported by developing new construction materials and architectural aspects in addition to current applications.
- Governments should play more roles to increase the awareness of climate change.
- More enforcement should be put into action in order to increase the use of renewable energy resources for heating and cooling purposes. Hence, climate change and global warming can be controlled, and their detrimental impacts can be reduced or even stopped.

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