Evaluation of Parameters Affecting Energy Efficiency of Vernacular Mardin Houses: A Case Study

Mardin Yerel Konutlarında Enerji Etkinliği Belirleyen Parametrelerin Değerlendirilmesine Yönelik Bir Çalışma

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ABSTRACT

This paper presents the bioclimatic characteristics of vernacular houses in Mardin City and a quantitative evaluation of parameters affecting energy efficiency. For the evaluation; the parameters of site, settlement density, optical and thermo-physical properties of the building envelope are covered. An existing house representing vernacular Mardin housing is selected and modelled with the surrounding settlement. The simulation is performed for a typical meteorological year. Five different cases are modelled to evaluate different parameters and simulated to calculate monthly heating and cooling energy demands. The results reveal the significance of each parameter for contributing to energy efficiency. The base case representing the existing settlement has been determined as the optimum case with minimum total energy demands though the results vary when heating and cooling demands are considered separately. Energy demands are strongly affected by thermo-physical characteristics but especially the use of massive materials in the envelope (up to 39.77%). Settlement scale parameters of site and settlement density change balance of heating and cooling demands but in total have limited influence on total energy loads. (1.79% and 1.52%) Increasing window to wall ratio from 4.88% to 10% have increased yearly total energy loads by 2.05%.

Keywords: *Energy efficiency; hot arid climate; Mardin; thermal mass; vernacular housing.*

ÖZ

Bu makale yerel Mardin konutlarının iklimsel özelliklerini değerlendirmekte ve enerji etkinliğini belirleyen parametrelerin analizini içermektedir. Yapılan parametrik analizlerde topoğrafya, yerleşme yoğunluğu, bina kabuğunun optik ve termofiziksel özellikleri değerlendirilmiştir. Var olan yerleşme içerisinden yerel konut dokusunu temsil eden bir ev seçilmiş ve çevresindeki yapılar ve topoğrafya ile birlikte modellenmiştir. Her bir parametrenin analizi için farklı modeller oluşturulmuş, bir yıllık bir periyotta simülasyon yapılarak her model için aylık ısıtma ve soğutma enerji yükleri hesaplanmıştır. Sonuçlar her parametrenin enerji etkinliğe katkısı açısından önemini göstermektedir. Temel durum olarak belirlenen var olan yerleşme dokusu toplamda minimum enerji yükünü sağlayarak optimum sonuçları vermiştir. Fakat ısıtma ve soğutma yükleri ayrı ayrı değerlendirildiğinde farklı sonuçlar elde edilmiştir. Bina kabuğunun özellikleri, bilhassa termal kütle kullanımının enerji yüklerini diğer parametrelerden çok daha fazla etkilediği belirlenmiştir. (%39.77'ye kadar) Yerleşme ölçeğindeki parametreler olan topoğrafya ve yerleşme yoğunluğu ise ısıtma ve soğutma yüklerini birbirine zıt şekilde etkileyerek var olan dokuda toplamda en az enerji yükünün sağlanmasına katkı sağlamaktadır. Saydamlık oranının %4.88'den %10'a çıkartılması ise yıllık toplam enerji yükünü %2.05 arttırmıştır.

Anahtar sözcükler: *Enerji etkinlik; sıcak kuru iklim; Mardin; termal kütle; yerel mimari.*

Introduction

Considering the current ecological crisis in which building sector hold a large share of responsibility, a shift in building practices approach towards a dialectical interaction with nature has become compulsory. As stated by Turan[1], current building practices is based on present mode of production which relies on the idea of an external nature outside of man and mastery over nature. In contrast to this, vernacular architecture presents us how the dialectical interaction with nature can be achieved. Vernacular buildings show great respect for their environment by using local materials and techniques taking the constraints imposed by climate fully into account.[2] It is clear that these buildings can not be copied morphologically as they were meant to serve under different cultural, economical, social and maybe even climatic conditions. It is necessary to understand the ways these buildings adapt to climate and analyze their bioclimatic characteristics under current conditions.

According to Mazouz and Zerouala[3] there are two tendencies seem to emerge in the various bioclimatic approaches to building and design. The first tendency focuses only on single buildings and tries to enhance their overall thermal performance by well known feature such as thermal mass, surface to volume ratio and shading devices. The second tendency takes good old vernacular solutions for granted, without the use of any analytical tool, copied even to their small details, and falling into the trap of pastiche and folklore. Yet an alternative approach seems possible. Such an approach would neither copy forms from the past nor treat buildings in isolation from their context, but generate forms by modulating environmental parameters through the use of design aids and tools. A holistic approach taking the parameters in different scales into account is necessary.

There are numerous studies made to review, classify and comment on the bioclimatic characteristics of vernacular architecture. (E.g. Coch, 1998[2]; Bouillot, 2008[4]; Sözen and Gedik, 2007[5]; Baran et al., 2011[6]; Vissilia, 2009[7]; Singh et al., 2011[8]) Most of the studies focus on 'learning from the vernacular' for the design of energy efficient and comfortable built environments. It is hard to distinguish and make clear statements about different characteristics and parameters for their contribution to thermal environment. Making a quantitative evaluation requires tools for measurement and/or simulation. And there are so many parameters to consider in different scales. Some measurement and simulation studies are made to evaluate energy efficiency and

thermal performance of vernacular buildings considering the interior spaces (e.g., Foruzanmehr et al., 2008[9]; Manioglu et al., 2008[10]; Singh. et al, 2010[11]; Oikonomou et al., 2011[12]; Cardinale et al, 2013[13]; Xiaoyu, 2014[14]) There are others focusing on the urban form and microclimate which is important for both indoor and outdoor thermal comfort. (E.g. Bourbia et al., 2004[15] and 2010[16]; Johansson, 2006[17]; Mazouz and Zarouala, 2013[3]; Taleb et al., 2013[18]; Andreau and Axarli, 2012[19] and Andreau, 2014[20]) The general findings show that compact urban forms and deep urban canyons create more comfortable outdoor spaces in hot arid climates. The shading through urban configurations is found to be more important than wind, for thermal comfort in hot and arid climate.

In this paper vernacular architecture of Mardin city that is located in the hot-arid climatic zone of Turkey is studied in this perspective. Through the modelling and simulation of a selected case study house with the surrounding settlement, bioclimatic parameters under settlement, building and materials scale are evaluated. This is a preliminary study to understand the weight of several parameters on the energy efficiency of vernacular housing and will be guiding the ongoing research on the energy efficiency of vernacular Mardin settlement. The parameters considered include site, settlement density, optical and thermo-physical properties of the building envelope.

Vernacular Mardin Settlement

A review of vernacular architecture in Turkey will present a rich variety of architectural characteristics developed in accordance with a range of climate types. Hot–arid climatic region having one of the most adverse conditions displays an open-air laboratory of vernacular architecture examples with passive design strategies. Mardin is one of the well preserved examples in hot-arid climatic region and it gives the impression of one whole structure with interweaving modular blocks, courtyards and irregular narrow streets. The vernacular settlement of Mardin is explained in terms of location, climate, settlement pattern, building form and materials in the following subsections.

Location and Climate

Mardin is located in Southeastern Anatolia and has the coordinates of 37.31° Northern latitude and 40.73° Eastern longitude. The local climate displays hot-arid region char-

[1] Turan, 1933, pp. 141-168.
[2] Coch, 1998, pp. 67-87.
[3] Mazous and Zarouala, 2013, pp. 3-13.
[4] Bouillot, 2008, pp. 287-299.
[5] Sözen and Gedik, 2007, pp. 1810-1816.
[6] Baran et al., 2011, pp. 609-619.
[7] Vissilia, 2009, pp. 1095-1106.
[8] Singh et al., 2011, pp. 2011-2022.
[9] Foruzanmehr et al., 2008, pp. 250-258.
[10] Manioglu et al., 2008, pp. 1301-1309.
[11] Singh et al., 2010, pp. 320-329.
[12] Oikonomou et al., 2011, pp. 669-689.
[13] Cardinale et al., 2013, pp. 590-598.
[14] Xiaoyu, 2014, pp. 215-227.
[15] Bourbia et al., 2004, pp. 249-262.
[16] Bourbia et al., 2010, pp. 343-347.
[17] Johansson, 2006, pp. 1326-1338.
[18] Taleb et al., 2013, pp. 747-762.
[19] Andreau and Axarli, 2012, pp. 354-363.
[20] Andreau, 2014, pp. 587-596.

Table 1. Mardin climatic data[21]

Climate data summary for Mardin		Temperature (°C)	Max	Min	Avg
Avg. Temperature	15.9 ℃	January	5,6	0,4	2,9
Avg. Humidity	49%	February	6,9	1,0	3,9
Prevailing Wind Direction	N-NE	March	11,1	4,2	7,6
Avg. Precipitation	696.5mm	April	17,0	9,4	13,2
Avg. Air Pressure	895.0 Mb	May	23,6	14,8	19,4
Avg. Maximum Temperature	19.9 ℃	June	30,3	19,9	25,5
Avg. Minimum Temperature	12.0 ℃	July	34,8	24,3	29,8
Mazimum Recorded Temperature	42.5 ℃	August	34,4	24,3	29,4
Minimum Recorded Temperature	-14.0 ℃	September	29,9	20,5	25,1
Avg. Maximum Precipitation month	January	October	22,6	14,3	18,2
Avg. Maximum Humidity Ratio	70% (January)	November	14,4	7,9	10,9
Avg. Minimum Humidity Ratio	28% (July)	December	7,8	2,6	5,1

Figures 1 and 2. Top and aerial views of Mardin city (from the archive of Yüksel Demir, 2015).

acteristics having hot and dry summers and cool winters with high precipitation. In summer the radiation intensity is so high that ground surface temperature could go up to 70°C. The diurnal temperature difference is high and the surface temperature drops to 15°C at nighttime. The northern mountains affect the climate significantly shielding the settlement from northern winds. The discomfort of hot arid summer days is partly mitigated by the mountain breezes (Table 1, Figures 1 and 2).

Settlement Pattern

The current settlement is on the middle and lower parts of the south-facing slope of Mazı mountain. The old citadel is located on the hilltop and the main settlement used today lays on the lower slope in a dense and stepped pattern. Current settlement pattern dates back to Artukid Dynasty and has a long-standing tradition. The geographi-

cal location and topography make this place very favorable in terms of defense, economy and ecology. The location permits creation of individual units and stepping terraces to have access to the sun. The katabatic winds are comforting during hot summer days. During the day the warm air in valley bottom rises while the cool air from mountain goes down creating a constant airflow. During nighttime the colder air descends from high plateaus towards valley bottoms and creates comforting cool night breezes for the settlement. This cold air accumulates in courtyards and helps to keep the buildings up to afternoon hours (Figure 3a, b).

The buildings are very densely settled minimizing the solar radiation access on building envelope. The massively constructed buildings crowded together provides maximum volume with minimum surface area exposed to the outside environment. The buildings are effectively shielded from east and west sides. The outdoor spaces

Figure 3. (a) Mardin settlement plan, **(b)** detail in larger scale.

within the settlement are mostly shaded by buildings and courtyard walls. The main streets are oriented in east-west axis. Vernacular solutions such as covered streets called 'kabaltı' are effective creating shaded, comfortable outdoor spaces. Kabalti is generally constructed between the family houses so they also display the social network in the city. The houses are constructed in line with the landscape creating a homogenized pattern. The ground floors open up to the street while the upper floors provide a view of the Mardin plain. This kind of terraced housing does not allow large plain city blocks. Since the city blocks are on sloped terrain and the depth is enough, the upper storeys could also be built on the soil. The terraces could easily be accessed from the upper floors and are frequently used for sleeping in summer.

Building Form and Materials

Building form is compact with minimum surface area to volume ratio for minimizing the interaction with the severe outdoor conditions. The compact courtyard form is used in most buildings. Open and semi-open spaces are created around courtyard. Courtyards with some greenery, shading and water modify the microclimate by lowering ground temperature and radiation. Almost all buildings in vernacular settlement are underground on northern side but some of them make use of totally underground cave like spaces. The settlement is on a soft calcareous rock formation that is easily hewn. In summer these spaces are cooler than anything that could be built on the surface.

The houses are built as single, two, three or four storeys that is determined by the level difference between the start and ending points of the city block. The storey height ranges from 3 to 5,5 meters.[22]

At nighttime cool air accumulates in the courtyards and as they are protected from hot arid winds and radiation, the houses can take advantage of this coolness until afternoon hours. Courtyards are also important for daylight

and ventilation. These houses have small windows on street facing façades and larger windows on courtyard facing façades. This window scheme is also a result of privacy concerns and it enables effective natural ventilation and minimizes radiation. Diffuse daylight from courtyard windows is provided while direct radiation is prevented. In the afternoons the cold air is dissipated and natural ventilation is induced by the stack effect of courtyard. Courtyard and building dimensions are very important parameters determining the effectiveness of these daylighting, natural ventilation and shading effects.

Building envelope is generally heavily constructed with locally available natural stone. This is a yellow limestone stone that is soft and easily shaped. It has lower density and lower thermal transmittance compared to concrete, granite and sandstone. Wall thicknesses vary between 0.80-2.0 m on the ground floor and 0.75-0.90 m on upper floors.[22] All exterior and interior floor covering is also made of this local Mardin stone. An often-ignored concept of thermal mass has significant effects on building microclimate in hot-arid climates. These thick walls and roofs have the ability to store heat energy, either sensible or latent. The heat storage helps to buffer temperature changes. According to Givoni[23] high thermal capacity in a shaded and insulated building can help lower indoor maxima by %35-45 of the outdoor ones when the building is unventilated. The research undertaken at I.T.U. for analyzing the performance of vernacular houses in Mardin with comparison to contemporary houses represents direct in-situ measurements during summer.[24] The massive vernacular buildings have much lower interior temperature swings and lower temperatures providing higher thermal comfort. This is a result of high thermal mass properties of these walls. Thermal mass is different from thermal transmittance and should be considered particularly for arid climates with high diurnal temperature swings. Many energy rating systems and standards include requirements based on thermal transmittance and related use of ther-

[22] Alioğlu, 2002, pp. 60.

[23] Givoni, 1994, pp. 145-169.   [24] Yılmaz, 2007, pp. 306-316.

mal insulation. These are based on steady state conditions and does not take into account the dynamic variations in thermal conditions by time. In the actual conditions, in accordance with the dynamic changes in outdoor conditions, the building envelope could absorb, store and release heat. The capacity of storing heat energy is related to the density and the specific heat capacity of the material and the relase is related to the thermal coductivity. This effect of thermal mass could help stabilizing indoor thermal conditions and it is most beneficial in the cases with high diurnal temperature differences. According to Meir and Roaf,[25] this property is becoming of ever-increasing importance as the climate is becoming less predictable and more adverse with extreme hot spells throughout the year and extreme cold spells in winter.

The openings are minimized in east, west and north oriented facades. But small openings are necessary in northern walls to induce natural ventilation from south facing openings. Mostly there are small openings located on the higher levels of walls. These are very effective for dissipating the hot air inside and also reducing direct radiation while providing daylight. Some buildings have large windows with shutters and smaller windows above them. So depending on the orientation and season the lower shutters are kept close while daylight and ventilation is supplied from upper small windows.

Methodology

For the evaluation of energy efficiency of vernacular Mardin housing a case study building to represent basic vernacular Mardin house is determined. The selected house is modelled including the settlement around and considering the site. This model is taken as the base case. Other cases are created to evaluate different parameters in terms of energy efficiency.

The selected house is in Ulu Cami district, also is on the same axe with the historical mosque Ulu Cami. It is a well-preserved traditional house and belongs to Secilmis family. The house has two floors and has an entrance to each floor from street level. The north entrance opens up to the first floor terrace and the second entrance from west opens up to the courtyard at the ground floor. The orientation is exactly to the south and the house has a great view of the Mardin plain. The service spaces are mainly on the ground floor while the living spaces are on the first floor. There are some small additions on the first floor around the terrace. The storage room is old but the kitchen and bathroom are added afterwards. There are 3 rooms and a semi-open space 'eyvan' on the first floor. Eyvan is recently closed by glass walls by the owner. Living spaces are all oriented to south. The house has a richness of space with
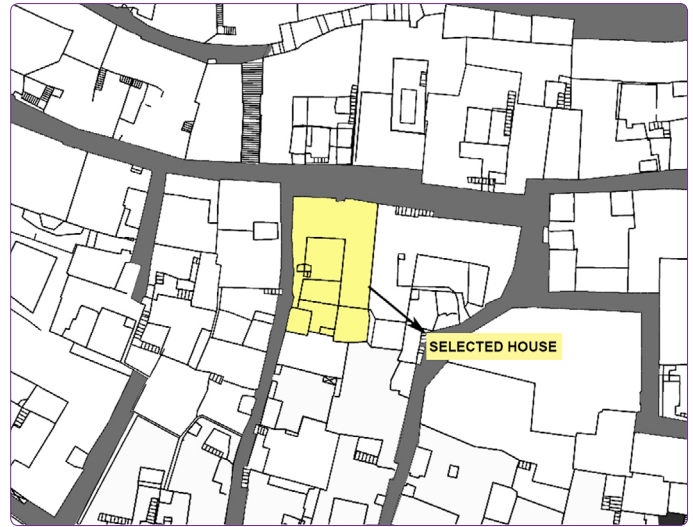
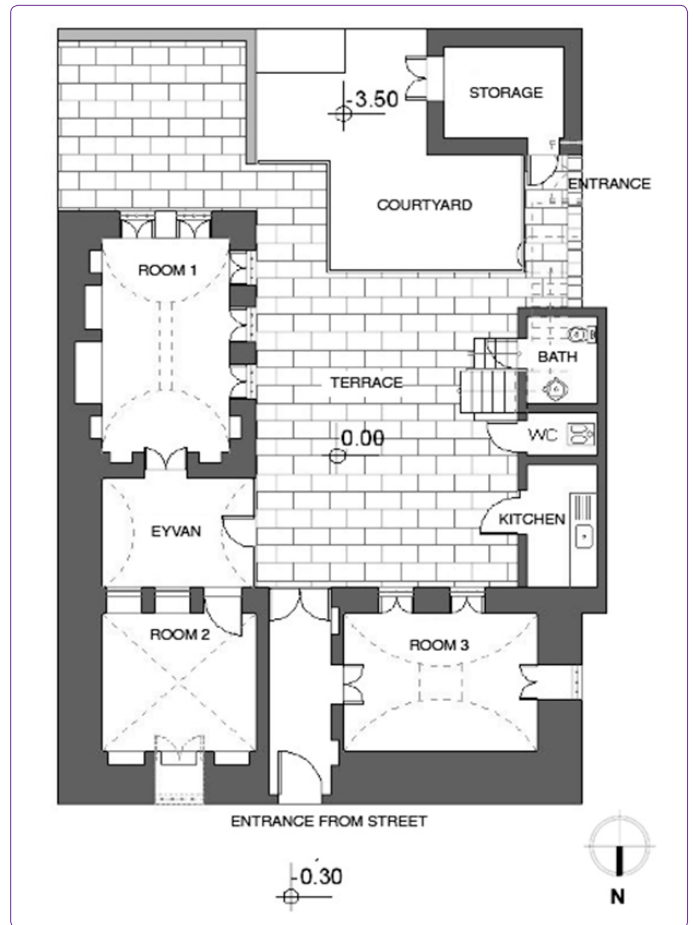

Figure 4. The selected house within the settlement plan.

Figure 5. The plan of the first floor (right).[26]

closed, semi-open and open spaces on both floors (Figures 4 and 5).

To analyze different parameters affecting energy efficiency the actual settlement is modelled through a dy-

[25] Meir and Roaf, 2003, pp. 1050-1055.

[26] Karagülle, 2009, pp. 334.

namic thermal simulation software DesignBuilder, which is actually an interface program using Energyplus simulation engine. The parameters considered for evaluation are, terrain slope, settlement density, thermal mass and window to wall ratio. For evaluation of each parameter a different model is created and for each model heating and cooling loads are calculated for a simulation period of one year. In total 5 different case study models are analysed taking the actual settlement as the base case.

For the modelling of the actual settlement around the case study house, the first step was to collect the topographic data. For this purpose the topographic maps are obtained and the terrain is modelled. The selected house is modelled in detail and the surrounding buildings are entered as closed volumes as they only affect the microclimate around the house. All the buildings are leveled according to the topography. For the surrounding houses and street geometries, the construction plans of the city are obtained. For the upper floors of surrounding houses panoramic photographs are used.

The ground floor is no more used by the occupants so is not also considered for energy calculations. Second floor is modelled in detail considering the materials, window shapes and thickness variations in the walls. Eyvan is modelled as a semi-open space, as it is in original. The room on the south, 'room 1' is the living room and other two rooms are modelled as bedrooms. Component blocks are used for the modelling of courtyard walls and the roof of eyvan.

The second case study model is created to analyse the effect of sloped terrain. The slope enables a terraced settlement so each house could gain radiation from south. This enables an optimum solution for heating but may also cause overheating in summer. This is one of the important parameters to evaluate In terms of whole year energy use, considering both heating and cooling. Case II, representing the case with flat terrrain is compared with the base case to understand the influence of the slope.

The actual settlement has a very high density, as in this case two facades of the house are adjacent to other houses and the street width is 5 meters on the north and 2 meters on the west side. The density of the settlement is a very important parameter defining the outdoor comfort conditions in the city and also the microclimate around the house. In this case only the effect on the interior conditions, the energy loads are considered. The effect of settlement density on outdoor comfort conditions should be dealt separately. For the sake of comparison Case III is modelled as a single building and compared with the base case (Figures 6 and 7).

The selected house is a well-preserved house having the main characteristics of traditional houses of Mardin. The envelope is massive made of a local limestone. The walls
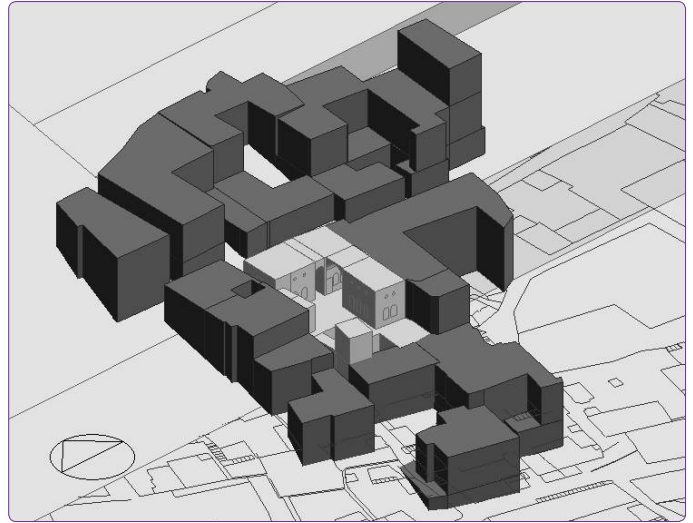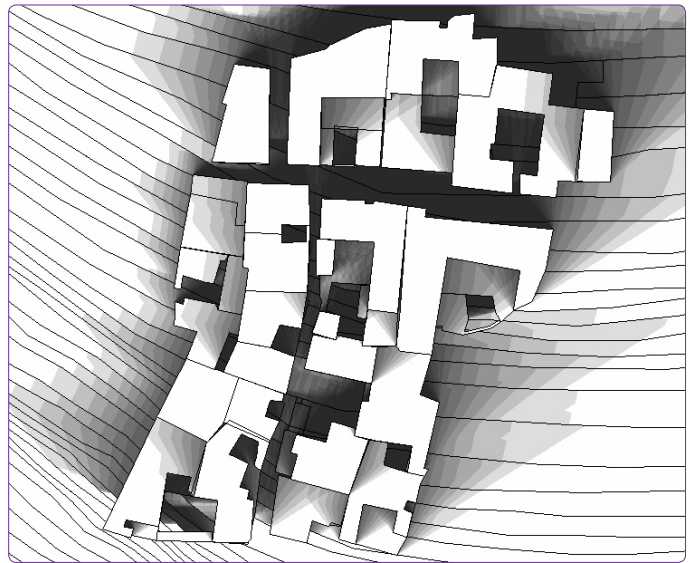

Figure 6. The simulation model.

Figure 7. The geometrical model.

are made of two layers of cut stone and crushed stone in between. The total thickness of the walls is 1 meter. The massive wall stabilizes the outdoor temperature swings by its thermal mass effect. The diurnal temperature range in this climate is high. The thermal inertia created by such a massive envelope is expected to be very effective on the thermal energy performance of these houses. In order to analyze this effect quantitatively the single house with massive envelope is compared with the fourth case study model: single building an identical plan and openings with insulated conventional walls. The wall detail used is a common one with plaster on both sides, concrete blocks and inner insulation of EPS. Table 2 shows the layers and thermophysical characteristics of the modelled walls for two cases.

The overall heat transfer coefficient of this insulated wall is 0.535 W/m²K and it is acceptable according to Turk-

Table 2. Physical and thermal properties of the modelled massive and conventional walls

MASSIVE WALL		CONVENTIONAL WALL	
Materials	**Thickness**	**Materials**	**Thickness**
Cut Mardin Stone	300 mm	Plaster	30 mm
Crushed Mardin Stone	400 mm	Medium weight concrete	120 mm
Cut Mardin Stone	300 mm	EPS thermal insulation	60 mm
		Plaster	30 mm
Total Thickness	1000mm	Total thickness	240 mm
U Value	0.70 W/m²K	U Value	0.53 W/m²K
Internal Heat Capacity	272.58 KJ/m²K	Internal Heat Capacity	53.22 KJ/m²K

Table 3. Yearly heating cooling and total energy loads for all cases

	BASE CASE: Actual Settlement	CASE II: Flat Terrain	CASE III: Single Building	CASE IV: S.B. Conv. Walls	CASE V: S.B & C.W. & 10% WWR
Heating Load (kWh)	3214,15	3363,27	2774,96	4146,4	3955,93
Cooling Load (kWh)	1119,17	1047,43	1624,37	2002,52	2761,25
Total (kWh)	4333,32	4410,7	4399,33	6148,92	6717,18

ish Code TS 825[27] as the upper limit for this climatic region is set as 0.60 W/m²K. For the massive wall the thermophysical characteristics are taken from the experimental study on the local stones of Mardin by Adin.[28] Based on this data the heat transfer coefficient of the 1 meter wide chest wall is calculated as 0.70 W/m²K. The internal heat capacities are 53.22 kJ/m²K for the insulated wall and 272.58 kJ/m²K for the massive wall (Table 2).

Vernacular Mardin houses have very low window to wall ratios. The selected house has an average WWR of 4.88% when the three living spaces (room 1, 2 and 3) are considered. This strategy lowers the radiation received by interior spaces and increases thermal comfort in summer conditions. In winter this might increase heating demands and so, is evaluated in terms of both heating and cooling demands. Case V, single building with conventional insulated walls and a window to wall ratio 10% is modelled and compared with case IV: single building with conventional insulated walls and a window to wall ratio of 4.88%.

Analysis and Results

The modelled five cases are simulated for a period of one year and heating, cooling energy loads are calculated. Monthly and yearly energy loads are used to create graphs

[27] TS 825, 2013.   [28] Adin, 2007, pp. 13-17.

for comparison. Figure 8 shows the charts for the compared cases. The first column shows the cases compared in schematic drawings and percentage change in yearly total energy demands. The second column shows the monthly total heating and cooling demands for the two cases compared. The yearly energy calculation results are presented in Table 3. In total the base case yields minimum loads though when heating and cooling loads are considered separately, case III: single building and case II: flat terrain yield lower energy loads respectively.

When the simulation results for the 'base case: actual settlement' and 'case II: flat terrain settlement' are compared (Fig. 8a), the difference in energy loads are low for both heating and cooling periods. The settlement on flat terrain yields 4.64% higher heating loads and 6.41% lower cooling loads than the actual settlement. In yearly total there is a 1.79% increase in total energy demand. As the sloping terrain lets each house to be less obstructed to sunlight, it increases the solar gains and thereby decreases the heating loads. For the same reason the increase of solar gains causes an increase in cooling loads (Table 3).

Comparing the results for 'case III: single building' with the 'base case: actual settlement', the heating loads have decreased and cooling loads have increased. The Figure 8b shows the monthly total energy loads for each case. In the case of single building there is no shading from the sur-
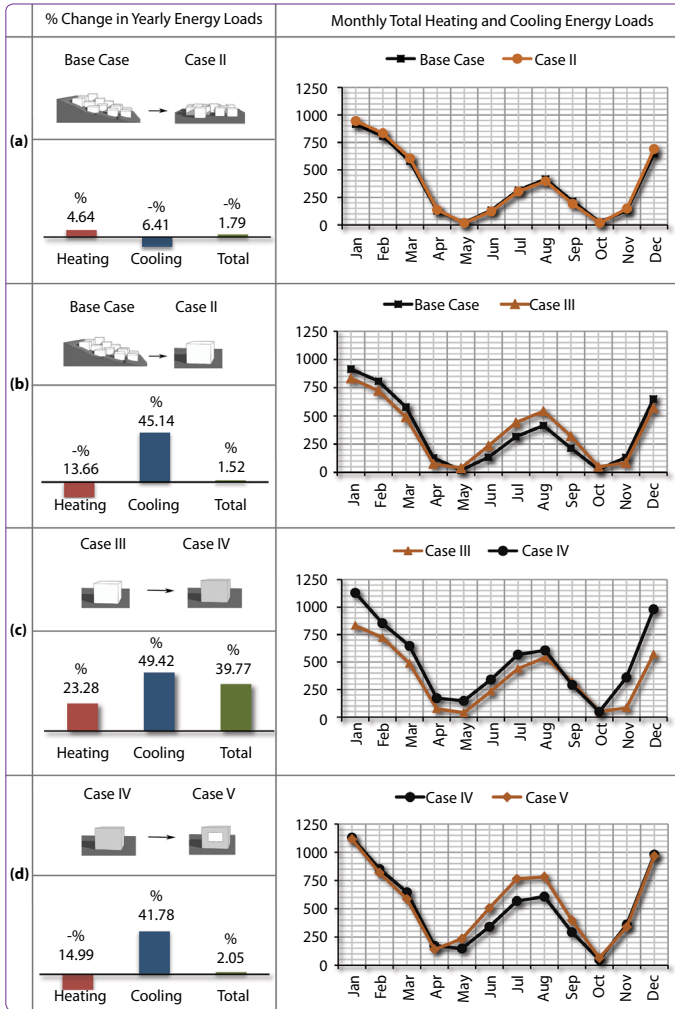
Figure 8. Charts showing % change in yearly energy use and monthly total heating and cooling energy loads for all compared cases.

decrease in heating loads is compensated by the increase in cooling loads, resulting in only 1.52% increase in total.

Cases III and IV, both single buildings, one with massive walls and other with conventional insulated walls with lower U value are compared in terms of their effect on energy demands. The detailed monthly energy loads for the two cases are presented in Figure 8c. It is seen that the massive envelope, although having a higher U value, yields better performance for both heating and cooling periods. The effect of massive walls in comparison to insulated walls on yearly total energy loads as percentages is also presented in 8c. In the case of conventional walls heating load increases by 23.28% and the cooling load by 49.42%. In total the increase in energy demand is 39.77%. This is a very significant result showing that the most significant parameter in terms of energy efficiency in vernacular Mardin houses seems to be the thermal capacity of the building envelope (Figure 8).

To understand the effect of thermal mass, hourly interior air temperatures in the 3 rooms for the summer and winter design days are reviewed. The results are very similar for the three rooms so only the results for room 3, calculated for the summer and winter design days are presented in Figure 9. On January 21st the interior air temperature in massive envelope case gets up to 5 degrees higher than the insulated envelope case. This shows that the thermal mass is also working efficiently during the heating period. On July 21st the interior air temperature in the massive envelope case is up to 4 degrees lower than insulated envelope case. In both days the massive envelope results in flatter interior air temperature curves. The use of thermal mass makes the interior space less susceptible to the changes in the exterior temperature in the considered climatic conditions.

For the evaluation of the parameter 'window to wall ratio', simulation results for case V: single building with con-

rounding buildings which has increased solar gains leading to decrease in heating demands and increase in cooling demands. Figure 8b shows the percentage change for heating, cooling and total energy demands. It can be seen that the
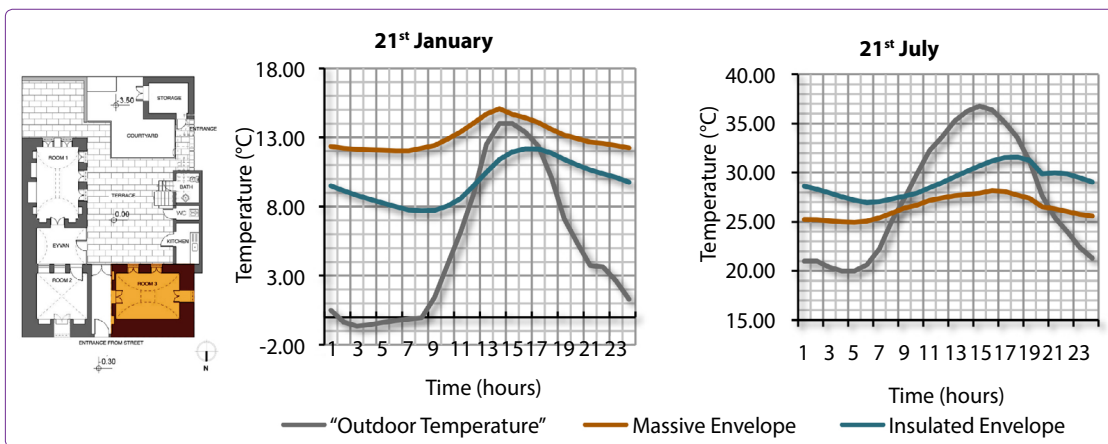

Figure 9. Hourly interior air temperature distribution in room 3, for the cases with massive and insulated envelopes (Cases IV and V) on the winter design day 21st January and summer design day 21st July.

ventional insulated envelope and a window to wall ratio of 10% is compared to case IV with a window to wall ratio of 4.88%. The results show that the increase in window area decreases heating loads by 14.99% and increases cooling loads by 41.78% (See Fig. 8d). As it is a climate where the cooling requirements are as significant as heating requirements, in total this causes an increase in total energy loads as 2.05%.

Discussion

When we compare all simulation results for five different cases, the actual settlement seems to yield minimum yearly total energy load although it does not have the minimum cooling or heating load. 'Case II: flat terrain' results in lowest cooling load and 'case III: single building with massive walls' has lowest heating loads. This means that the inclusion of surrounding buildings lowers the cooling loads and increases heating loads. This would be a perfect strategy for cooling if heating loads were not also significant. The addition of slope enables a higher amount of radiation thus lowering heating loads. And in total sloped dense settlement (base case) creates an optimum condition when both heating and cooling demands considered with lowest total energy load. This settlement pattern creates a balance between the required radiation and shading according to the seasons. The orientation of the slope towards the south is crucial for this balance as the radiation from this direction is easiest to control in summer and has lower solar altitude in winter.

Figure 10 shows the total energy loads for five cases simulated. The single building with massive walls resulted in the second lowest of total loads and also lowest heating load. So the addition of the settlement has lowered cooling loads and increased heating loads. It is important to note that what we compare here is the energy loads for the interior of the house, the settlement probably has significant effects on the outdoor thermal comfort condi-

tions in the city and this should be analyzed with different tools. The third lowest total load is by the no slope settlement case. In this case the cooling load is lowest, due to the maximized shading of surrounding buildings and consequently the heating load has increased.

The most significant change in energy loads is due to the change in building envelope. This indicates the effectiveness of thermal mass in this climate. The change from massive walls to conventional insulated walls increases the energy loads by 39.77%. Despite the conventional insulated walls having lower heat transfer coefficient values, the heat transfer is more effectively controlled by the use of massive walls, the effect of heat storage. This strategy works distinctively in conjunction with the high diurnal temperature differences in this climate.

Conclusion

Vernacular houses are designed and constructed within the limits of local possibilities resources and knowledge. The local limits have resulted in architecture with limited impact on nature. One of the key local inputs is the climate. Vernacular houses' design in accordance with climate determines the energy demand for heating and cooling as well as thermal comfort in indoor and outdoor spaces. In this research vernacular houses of Mardin have been evaluated for several parameters under different scales, in terms of yearly energy demand for heating and cooling. The design strategies are shaped by various forces such as social, cultural, defensive as well as climatic factors. This research is significant for interpreting vairous parameters in terms of their contribution to energy efficiency. The results reveal a clear significance of massive building envelope for reducing especially cooling but also heating demands. Unfortunately this is an ignored concept by building energy regulations in Turkey. The use of thermal mass in hot-arid climate zone should be evaluated in detail and be integrated into the national building energy
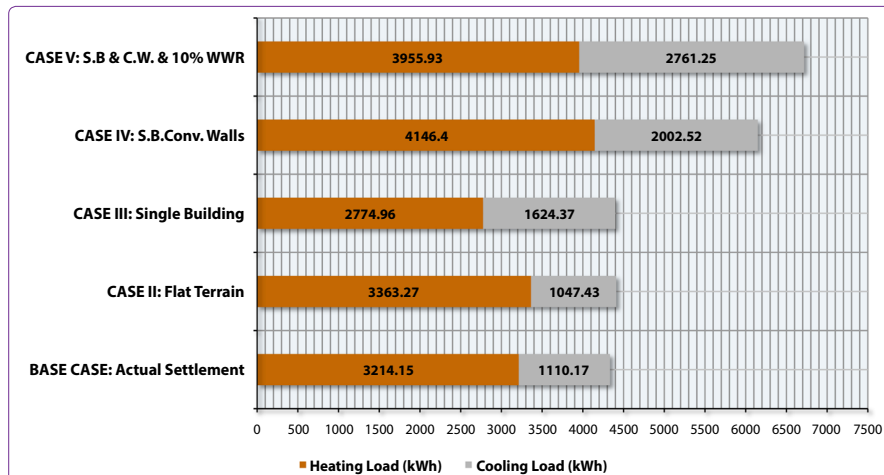

Figure 10. Yearly total loads for all cases.

regulations. According to the results, the settlement scale parameters like site and settlement density have less impact on energy demands. The settlement scale parameters could be more significant when outdoor thermal comfort conditions are considered. This requires microclimate-modelling tools and is the subject of the ongoing research on vernacular Mardin settlement.

Acknowledgements

References

Adin, H. (2007) "Mardin ve Midyat'ta Kullanılan Bina Yapı Taslarının Bazı Fiziksel Ozellikleri", Mühendis ve Makina, 48:570, pp. 13-17.

Alioğlu, F. (2000) "Mardin Şehir Dokusu ve Evler", Tarih Vakfı Yayını, İstanbul.

Andreou, E., Axarli, K. (2012) "Investigation of urban canyon microclimate in traditional and contemporary environment: Experimental investigation and parametric analysis", Renewable Energy, 43, pp. 354-363.

Andreou, E. (2014) "The effect of urban layout, street geometry and orientation on shading conditions in urban canyons in the Mediterranean", Renewable Energy, 63, pp. 587-596.

Baran, M., Yıldırım, Yilmaz, M. A. (2011) "Evaluation of ecological design strategies in traditional houses in Diyarbakır", Journal of Cleaner Production, 19, pp. 609-619.

Bouillot, J. (2008) "Climatic design of vernacular housing in different provinces of China", Journal of Environmental Management, 87, pp. 287-299.

Bourbia, F., Awbi, H.B. (2004) "Building cluster and shading in urban canyon for hot dry climate, Part 1: Air and surface temperature measurements", Renewable Energy, 29, pp. 249-262.

Bourbia, F., Boucheriba, F. (2010) "Impact of street design on urban microclimate for semi arid climate (Constantine)", Renewable Energy, 35, pp. 343-347.

Cardinale, N., Rospi, G., Stefanizzi, P. (2013) "Energy and microclimatic performance of Mediterranean vernacular buildings: The Sassi district of Matera and the Trulli district of Alberobello", Building and Environment, 59, pp. 590-598.

Coch, H. (1998) "Bioclimatism in vernacular architecture", Renewable and Sustainable Energy Reviews, pp. 67-87.

Edwards, B., Sibley, M., Hakmi, Land, M.P. (2006) "Courtyard Housing: Past, Present & Future", Taylor and Francis, New York.

Fathy, H. (1986) "Natural Energy and Vernacular Architecture: Principles and examples with Reference to Hot Arid Climates", United Nations University Press, Tokyo.

Foruzanmehr, A. (2012) "The wind-catcher: users' perception of a vernacular passive cooling system", Architectural Science Review, 55:4, pp. 250-258.

Givoni, B. (1994) "Passive and low energy cooling of buildings", Van Nostrand Reinhold Company, New York, pp. 145-169.

Imamoglu, V. (1980) "Microclimatic elements of homes in Turkish arid zones", Ed.: G. S. Golany, Housing in Arid Lands: Design and Planning, The Architectural Press, London, pp. 45-74.

Johansson, E. (2006) "Influence of urban geometry on outdoor thermal comfort in a hot dry climate: A study in Fez, Morocco", Building and Environment, 41, pp. 1326-1338.

Karagülle, C. (2009) "Yerel verilerin konut tasarım sürecinde değerlendirilmesi: Mardin örneği", Doctoral Dissertation, İstanbul Technical University Graduate School of Science, Engineering and Technology, pp. 334.

Manioglu, G., Yılmaz, Z. (2008) "Energy efficient design strategies in the hot dry area of Turkey", Building and Environment, 43, pp. 1301-1309.

Mazouz, S., Zarouala, M. S. (2013) "The Derivation and Re-Use of Vernacular Urban Space Concepts", Architectural Science Review, 42:1, pp. 3-13.

Meir, I.A., Roaf, S.C. (2003) "Thermal Comfort-Thermal Mass: Housing in hot dry climates", Indoor Air 2002 Proceedings, 9th International Conference on Indoor Air Quality and Climate, Santa Cruz, pp. 1050-1055.

Oikonomou, A., Bougiatioti, F. (2011) "Architectural structure and environmental performance of the traditional buildings in Florina", NW Greece, Building and Environment, 46, pp. 669-689.

Singh, M.K., Mahapatra, S., Atreya, S. K. (2011) "Solar passive features in vernacular architecure of North-East India", Solar Energy, 85, pp. 2011-2022.

Singh, M.K., Mahapatra, S., Atreya, S. K. (2010) "Thermal performance study and evaluation of comfort temperatures in vernacular buildings of North-East India", Building and Environment, 45, pp. 320-329.

Sözen, M. Ş., Gedik, G. Z. (2007) "Evaluation of traditional architecture in terms of building physics: Old Diyarbakir houses", Building and Environment, 42, pp. 1810-1816.

Taleb, D., Abu Hijleh, B. (2013) "Urban heat islands: Potential effect of organic and structured urban configurations on temperature variations in Dubai", UAE, Renewable Energy, 50, pp. 747-762.

Turan, M. H. (1983) "Architectural and environmental adaptation in slope settlements", Ed.: G. S. Golany, Design for Arid Regions, Van Nostrand Reinhold Company, New York, pp. 141-168.

Vellinga, M. (2013) "The Noble Vernacular", The Journal of Architecture, 18:4, pp. 570-590.

Vissilia, A. M. (2009) "Evaluation of a sustainable Greek vernacular settlement and its landscape: Architectural typology and building physics", Building and Environment, 44, pp. 1095-1106.

Xiaoyu, D., Bokel, R., Dobbelsten, A. (2014) "Building microclimate and summer thermal comfort in free-running buildings with diverse spaces: A chinese vernacular house case", Building and Environment, 82, pp. 215-227.

Yilmaz, Z. (2007) "Evaluation of energy efficient design strategies for different climatic zones: Comparison of thermal performance of buildings in temperate-humid and hot-dry climate", Energy and Buildings, 39, pp. 306-316.

TS 825, (2013) "Thermal insulation requirements for buildings".

Url-1. http://www.weatheronline.co.uk/, (accessed on 10.05. 2018).