A Comparative Analysis of Typical Pakistani Homes for Energy Consumption - With and Without Courtyards

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Abstract
A major portion of world's energy is being consumed by buildings (roughly 35%-40%), out of which a large amount is utilized by the air conditioning equipment. Current Pakistani home designs do not factor in local climatic conditions as much as they should be to enhance the thermal comfort and conserve energy. Passive cooling techniques such as "Courtyards" can be incorporated into existing designs to decrease the thermal loads. This research compared energy efficiency by adding a standardized courtyard into a typical residential unit of two housing societies of Lahore, Pakistan. The background and importance of courtyard in a residential unit are discussed in the paper. Necessary data collection related to climatic conditions of Lahore and residential by-laws is conducted. The existing housing units are compared with respect to their thermal performance, ventilation and daylight factor response by using the *Ecotect*® software. The monthly and annual cost savings in electricity bills are analyzed. Finally, the design proposals are generated for residential units with courtyards by strictly following the by-laws of the respective housing societies.

Keywords
Passive Techniques, Courtyards, Energy consumption, Energy efficiency

1. Introduction

The rising use of energy is a major challenge for the worlds' population nowadays. A significant increase in the use of air conditioning equipment has been identified all around the world. Around 40% of world's energy production is being consumed by buildings. A rapid increase in the construction of domestic buildings and rising living standards are considered to be the main causes of increasing energy demands (Samar *et al.*, 2016). The residential housing societies in Pakistan are mostly designed without considering local climatic conditions. The passive cooling in historical buildings provides a basis of inspiration for sustainable development in the modern world. Passive cooling techniques can reduce the cooling load thereby decreasing the required size of air conditioning equipment. As one of the primeval forms of architecture, "Courtyard" may be an appropriate passive cooling technique suitable for any type of building be it residential, institutional or commercial (Samar *et al.*, 2016).

Out of the many primordial engineering techniques, "courtyard or patios" are among the most significant.

Reynolds (cited in Samar et al., 2016) alludes to patios as "exceptional spots that are outside yet verging on inside, open to sky, more often than not in contact with the earth, yet encompassed by rooms." It is the patio shape that is of enthusiasm to this study. Existing research provides the following main findings on the influence of courtyard geometry on air flow and thermal comfort (Samar et al., 2016):

1. Rooms confronting one courtyard and having single side characteristic ventilation have low indoor air velocities. The presence of more than one courtyard gives better ventilation to the focal cross ventilated rooms.
2. The ground floor rooms are constantly cooler freely of the introduction and the air velocity values on top-floor rooms.
3. The marginally higher air velocity on the top floor is immaterial in perspective of lessening the negative impact of the sun oriented radiation over the rooftop and façade.

Courtyards are beginning to play a major role in increasing the energy efficiency of structures. In the past, they have been used for improving the natural lighting and increasing the natural ventilation and thermal relief of structures. It is a space utilized for various exercises and functions. One example of this would be the use of a *Jaalis*. *Jaalis* are little openings on the wall that can be made from perforated stone or latticed screens. They can successfully substitute the primary function of glass, which is to provide a visual opening from the interior of the structure to the exterior of the structure. In addition, *Jaali*s are more effective than glass at controlling both glare and warmth, accomplishing better style, and offering increased protection and security (Mumtaz, 1985)

Courtyards in tropical districts are more associated with the open-air environment and they have a permeable composition. Conversely, courtyards located in regions conducive to extreme heat and cold are constructed to be more shut off and shielded from these unforgiving elements. In instance of utilizing common components, distinctive sorts of vegetation and characteristic components are utilized as a part of hot parched atmospheres to adjust nature. Be that as it may, in different atmospheres, the dampness or cooling impact of characteristic components is not required (Taleghani *et al.*, 2012).

In general, passive systems are helpful for affordance of warm solace with low-energy, from the point of view of three environment parameters: temperature, humidity, and air changes. While 100% "thermal solace" may not be conceivable through latent cooling, it is conceivable to decrease the top vitality load extensively. The building envelope's warm mass and proficient air-snugness proved beneficial in both the summer and the winter. In the summer, it brought about better protection from the less positive climatic states of "cool" or "warmth" from outside amid summer. In the winter, heat created by common indoor variables, such as gear, people, and nursery impact, was sealed inside the structure due to its air-snugness (Tungnunga, *n.d.*).

In Pakistan, the housing societies for middle and upper class families offer homes on plot sizes of 2250 ft^2, 2700 ft^2, 3150 ft^2, and 4500 ft^2, and 9000 ft^2. There are currently three methods of house delivery that these housing societies offer the consumers in Lahore. The first is the traditional method where the housing society constructs the living arrangements and offers them for sale as-is, with no input from the potential consumer. In another house delivery method, the housing societies work with the consumer and construct a house to their specifications. The third delivery method is the conventional sale of land, where the housing society sell a plot and allow the buyer to construct their own home. Each housing society have its own set of by-laws dictating the allowable development potential. Some frequent regulations in housing by-laws include the measure of region that can be secured, the height of the building, and the width of open spaces on all sides, etc. (Qureshi, 2015).

This research study compared housing by-laws of two major housing societies in Lahore, Pakistan, namely the *Lahore Development Authority* (LDA, a public housing) and *Defense Housing Authority* (DHA, a private housing) with reference to passive energy measures, especially the courtyards. It then compared two design proposals with and without incorporating the courtyards and compare their energy performance through computer simulations.

2. Objectives and Scope

The objectives of this study are as follows:

1. Comparative study of bylaws of two housing societies of Lahore (LDA and DHA) with respect to energy consumption with and without adding courtyard.
2. Incorporation of traditional passive elements i.e. courtyard, into prevailing trends of residential sector in Lahore to increase the ventilation and reduce thermal load, thereby ultimately decreasing the energy consumption of the house.

This study is limited to 4500 ft^2 (1 Kanal) residential houses only. LDA's Guldasht Town and DHA's Phase-7 were the sites selected for this research.

3. Methodology and Results

3.1 Comparison of Housing By-Laws

Standing rules or bylaws are the guidelines set up by any nearby power, enterprise, association or authority to direct itself and to have power over the activities of its individuals. By-laws decide the rights of tenants and they give the strategies by which these rights can be executed. Printed copies of housing by-laws were obtained from both LDA and DHA. They were thoroughly reviewed to identify the major design requirements. A comparison is shown in Table 1.

Table 1: A Comparative Analysis of LDA and DHA By-laws

LDA By-laws	**DHA By-laws**
Ground floor should cover 65% of total plot including car porch and First floor shall not exceed 75% of the total permissible area of the ground floor.	Ground floor should cover 60% of total plot including car porch and First floor shall not exceed 75% of the total permissible area of the ground floor.
Clear Space for 4500 ft^2 House	
Front: 15'	Front: 1f' 9"
Rear: 7'	Rear: 5' 5.5"
Side: 5'	Side: 5' 4.5" (On both sides)
Specific Requirements for Courtyards	
None	None
Specific Requirements for Energy Efficiency Measures	
None	None

The comparison of by-laws clearly indicate that most of their clauses fulfil zoning and basic architecture requirements. They do not stipulate any conditions that can results in energy savings.

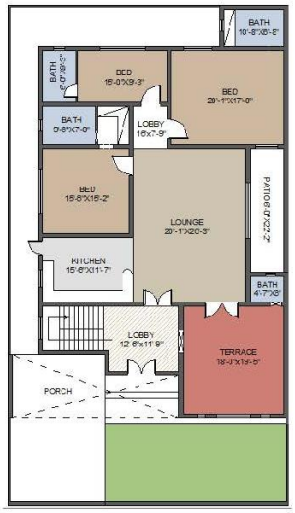
3.2 Design Proposal – Inclusion of Courtyard

Our design proposal is based on accommodation of a standardized courtyard in the existing residential units of LDA and DHA, while remaining within the residential bylaws of respective societies. A courtyard is provided according to the minimum standard criteria extracted from residential courtyard housing codes and research work performed on different courtyard sizing ratios. The following provisions are intended to encourage the construction of courtyard housing as an attractive and live-able alternative to other forms of multifamily housing development, by providing alternatives to certain development standards of this Zoning Code as incentives (see Table 2).

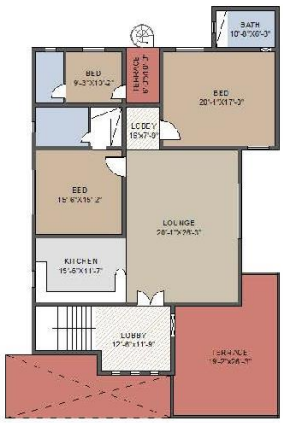
Table 2: Design Proposal for Adding Courtyards to Standard Home Design (Samar et al., 2016)

The common open space shall be designed as a central courtyard or interconnected courtyards. The common open space shall be at least 15 percent of the lot.
Courtyard proportions shall not be less than 1:1 between the width of the courtyard and height.
Private open space is required for each residential unit and shall be no less than 90 square feet with a minimum dimension of 6 feet in each direction.

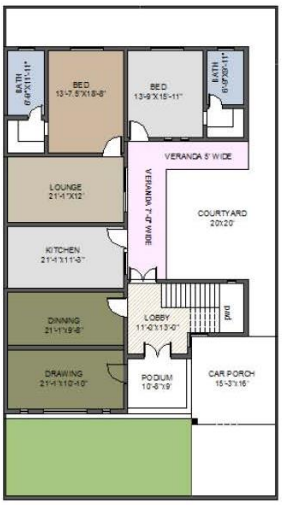
As the common open space shall be at least 15 percent of the plot size hence 15% of 4500 ft^2 = 675 ft^2. Hence the proposal includes a 25ft x 25 ft square courtyard. As Courtyard proportion should be 1:1 between the width of the courtyard and height of the building, so we take 25 feet for both width and height of building. Figures 1 and 2 show the "existing" and "proposed" floorplans for 4500 ft^2 houses for both LDA (1 proposal) and DHA (2 proposals) housing societies.



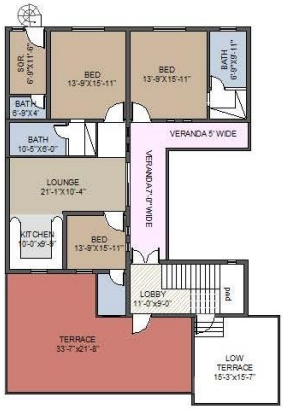
LDA – Existing Design - Ground Floor Plan



LDA – Existing Design - First Floor Plan

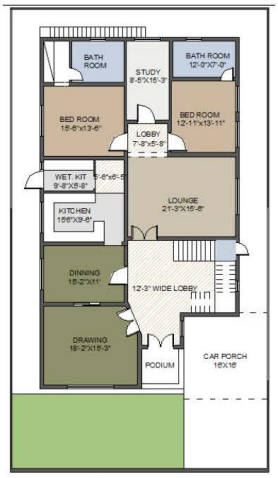


LDA – Proposed Design - Ground Floor Plan

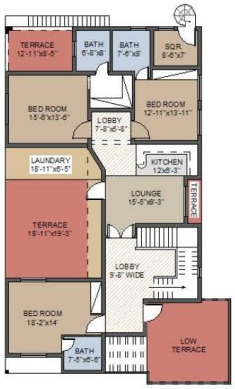


LDA – Proposed Design - First Floor Plan

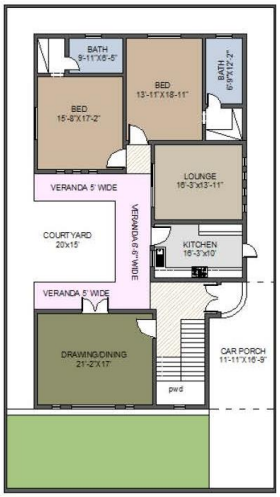
Figure 1: Existing and Proposed Floor Plans for a 4500 ft^2 House using LDA By-laws

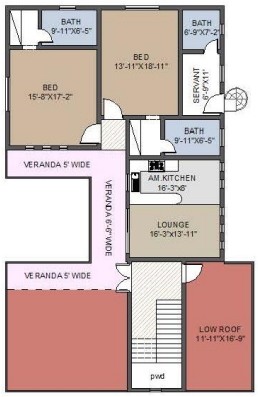


DHA – Existing Design - Ground Floor Plan



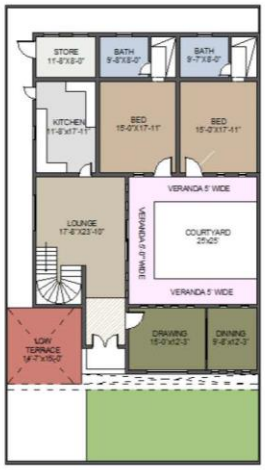
DHA – Existing Design - First Floor Plan

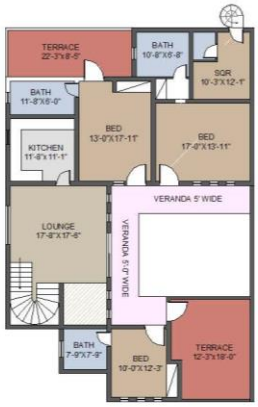




Proposed Design - Ground Floor Plan – Proposal.1

DHA – Proposed Design - First Floor Plan – Proposal.1





DHA - Proposed Ground Floor Plan – Proposal.2

DHA - Proposed First Floor Plan – Proposal.2

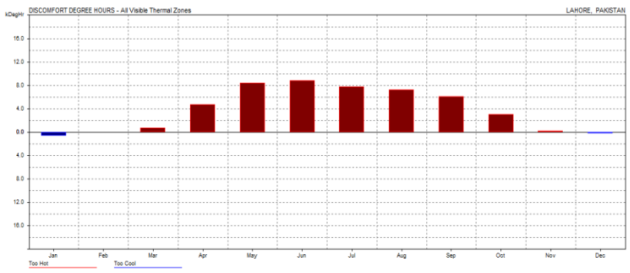
Figure 2: Existing and Proposed Floor Plans for a 4500 ft^2 House using DHA By-laws

3.3 Energy Simulation Results

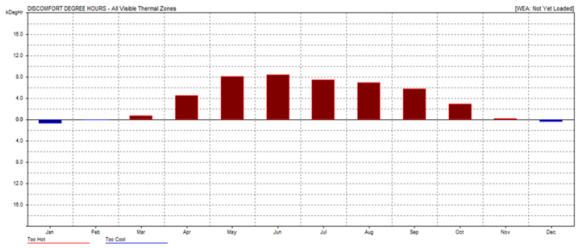
There are three types of analysis which were performed on existing and proposed units of both LDA and DHA.

3.3.1 Monthly Thermal Load Analysis

Monthly Load Analysis is a part of Thermal analysis that describes the discomfort degree hours either hottest or coolest. As the climate of most of the big cities of Pakistan is hot and humid that is why results of summer calculations are preferred. This analysis was performed on both existing and proposed units of LDA and DHA. Figure 3 shows the discomfort degree hours throughout the year. The blue bar is for coolest discomfort hours and the red bar depicts the hottest discomfort hours. The trend of graphs show that January and December are the coolest months while from March to November; some ups and downs in hottest degree hours are observed. By observing the total hottest degree hours of both existing and proposed layouts it was concluded that there is a reduction of **1874** too hot degree hours.



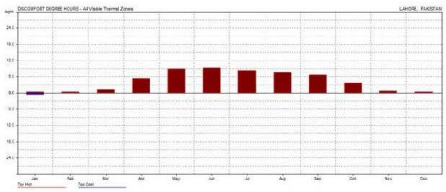
Monthly Discomfort Hours for LDA Proposed Unit



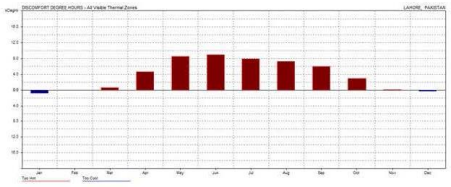
Monthly Discomfort Hours for LDA Existing Unit

Figure 3: Monthly Discomfort Hours for LDA Existing and Proposed Units

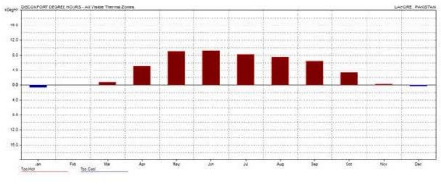
The same analysis was done for DHA units. As depicted in Figure 4. It was concluded that there is reduction of 6755 hours in hottest hours for proposal-1 while a reduction of 3647 hours for the proposal-2 for DHA. Although both the proposals satisfy our objective of reducing the thermal gain of the existing unit; yet we chose proposal -1 because it fulfills the maximum bylaw criteria in DHA.



Monthly Discomfort Hours for DHA Existing Unit



Monthly Discomfort Hours for DHA Proposal-1



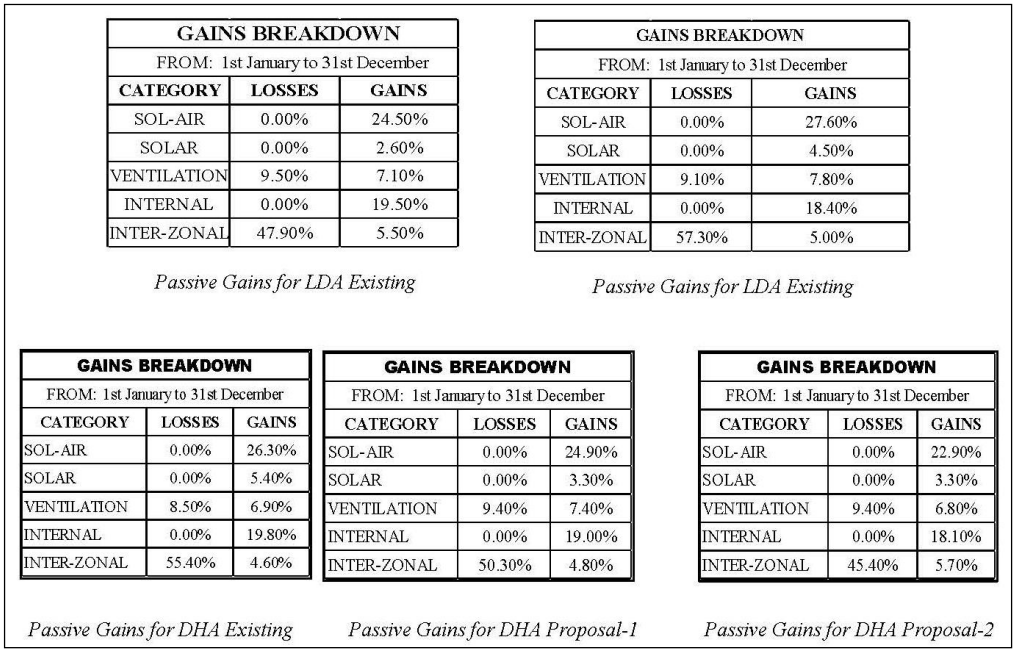
Monthly Discomfort Hours for DHA Proposal-2

Figure 4: Monthly Discomfort Hours for DHA Existing and Proposed Units

3.3.2 Passive Gain Breakdown Analysis

Passive gains breakdown analysis has been done for existing and proposed units of LDA and DHA. This

analysis provides amount of gains and losses of different categories i.e. fabric, solar, sol-air, ventilation, internal and inter zonal of the model. Courtyard provision will focus on Solar-air, solar and ventilation gains/losses. Results indicate lesser gains and losses in proposed units which incorporate courtyards compared to existing units. Results are shown in Figure 5.



GAINS BREAKDOWN		
FROM: 1st January to 31st December		
CATEGORY	LOSSES	GAINS
SOL-AIR	0.00%	24.50%
SOLAR	0.00%	2.60%
VENTILATION	9.50%	7.10%
INTERNAL	0.00%	19.50%
INTER-ZONAL	47.90%	5.50%

Passive Gains for LDA Existing

GAINS BREAKDOWN		
FROM: 1st January to 31st December		
CATEGORY	LOSSES	GAINS
SOL-AIR	0.00%	27.60%
SOLAR	0.00%	4.50%
VENTILATION	9.10%	7.80%
INTERNAL	0.00%	18.40%
INTER-ZONAL	57.30%	5.00%

Passive Gains for LDA Existing

GAINS BREAKDOWN		
FROM: 1st January to 31st December		
CATEGORY	LOSSES	GAINS
SOL-AIR	0.00%	26.30%
SOLAR	0.00%	5.40%
VENTILATION	8.50%	6.90%
INTERNAL	0.00%	19.80%
INTER-ZONAL	55.40%	4.60%

Passive Gains for DHA Existing

GAINS BREAKDOWN		
FROM: 1st January to 31st December		
CATEGORY	LOSSES	GAINS
SOL-AIR	0.00%	24.90%
SOLAR	0.00%	3.30%
VENTILATION	9.40%	7.40%
INTERNAL	0.00%	19.00%
INTER-ZONAL	50.30%	4.80%

Passive Gains for DHA Proposal-1

GAINS BREAKDOWN		
FROM: 1st January to 31st December		
CATEGORY	LOSSES	GAINS
SOL-AIR	0.00%	22.90%
SOLAR	0.00%	3.30%
VENTILATION	9.40%	6.80%
INTERNAL	0.00%	18.10%
INTER-ZONAL	45.40%	5.70%

Passive Gains for DHA Proposal-2

Figure 5: Passive Gain Breakdown Analysis for DHA Existing and Proposed Units

3.3.3 Day Light Factor Analysis

Day lighting factor analysis was conducted to calculate the amount of light coming through the courtyard – to determine if we are getting recommended lux or not? If we get more lux than required, then it can be controlled by using internal curtains/blinds. In case of getting less amount of lux, we need to provide artificial lighting in order to meet the minimum criteria of lighting levels in spaces. Three spaces are considered; lounge, bed room and kitchen as they are directly getting the light from the courtyard. After comparing these spaces of existing and proposed designs one we can find out the differences. This daylight analysis has been performed at the height of working plane i.e. 3 feet for a residential building. In the LDA proposed unit the recommended lux is achieved in both bedroom and lounge but in kitchen recommended light levels are not achieved so we need to do artificial lighting for gaining the required light levels. In the existing DHA house the recommended lux is only achieved in bedroom and lounge. However, both revised design proposals found to provide the required lux levels.

4. Conclusions

Following are main findings and conclusions of this study. Stage -1 analysis assimilates the comparative analysis results of existing LDA and DHA 4500 ft^2 residential units. The analysis, based on thermal loads of the units, are compared on seasonal basis. Monthly discomfort load analysis concludes that existing LDA units are more suitable for summers while existing DHA is comfortable in the winter. The annual and monthly billing costs for existing DHA units seemed to be higher than the existing LDA units. The difference in billing cost for LDA and DHA units is PKR 17,60,000 for 1000 houses of the respective societies while for next 20 years this difference may reach to PKR 352,500,000. Stage-2a illustrates the comparative analysis results of existing LDA unit and its proposal with courtyard. Monthly discomfort load analysis concludes that the proposed unit of LDA is more suitable for both summers and winters over the

existing unit. The proposed LDA unit is capable of decreasing 1476 hottest hours. The difference in billing cost for LDA existing and proposed units is PKR 33,601,000 for 1000 houses. While over the next 20 years the difference will rise to PKR 672,020,000 for proposed LDA unit. Stage-2b depicts the comparative analysis results of existing DHA unit and its proposal with courtyard. Monthly discomfort load analysis results in concluding that the proposed DHA unit (Proposal-2) is more suitable for summers, while the existing unit is more appropriate for winters as it has more heat gain than the proposed unit. The proposed DHA unit is capable enough of decreasing 3646 hottest degree hours annually. Passive results show that the proposed DHA unit offers a ventilation increase over the existing unit. This can be attributed to the addition of a courtyard. Moreover, a 5.32% reduction in solar air, 38.8% reduction in solar gain, and 6.75% increase in ventilation is achieved in DHA proposal-2. Annual cost savings are determined by simulation of the developed models on mix-mode system which gives the maximum heating and cooling loads of the building. We focused on cooling loads as summer is the dominant season in the region. Hence, results are quoted considering the savings in air conditioning load of the residential units. The prices are quoted according to the standard rates implemented by local authorities for billing purposes.

Table 3: The calculation of Annual Cost Saving as per the reduction in KWh consumption

ANNUAL SAVING					
RESIDENTIAL UNITS	**Kwh**	**BTU**	**TON**	**PRICE Rs.**	**SAVINGS**
LDA EXISTING	3717	12683087.44	3.19	55756	**33601**
LDA PROPOSED	1477	5039593.307	1.27	22155	
DHA EXISTING	3834.4	13083512.5	3.29	57516	**34876**
DHA PROPOSED-2	1509.3	5149989.738	1.29	22640	

Table 4: The Calculation of Cost Saving as per Reduction in KWh for Hottest Month

FOR JUNE AS A HOTTEST MONTH					
RESIDENTIAL UNITS	**Kwh**	**BTU**	**TON**	**PRICE Rs.**	**SAVINGS Rs.**
LDA EXISTING	814.2	2778162.312	0.70055	12213	**5320**
LDA PROPOSED	459.48	1567797.193	0.39	6893	
DHA EXISTING	837.08	2856218.465	0.72	12557	**5495**
DHA PROPOSED-2	470.77	1606344.157	0.4	7062	

Hence it can be concluded that by reviving courtyards; the thermal performance of the residence will improve. Moreover, increased ventilation is achieved followed by recessed use of mechanical cooling which reduces the energy billing costs.

5. Acknowledgements

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