REVIVING COURTYARD CONCEPT USING ELECTROCHROMIC GLAZING SYSTEM IN RESIDENTIAL BUILDING - THE CASE OF AMMAN CITY

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ABSTRACT

This research investigates the vitality advantages and future capability of using Electrochromic Glazing (ECG) System in sustainable courtyards in residential buildings inside the climatic states of the Amman city at the concept stage. This research considers the applied methodology to improve sustainability of courtyard, considering solar irradiation and buildings energy needs for cooling and heating. The Revit “energy modeling software” programming is utilized to evaluate the energy efficiency, chiefly the decreases in lighting, “heating, ventilating, and air conditioning” (HVAC), for various states and contrast that to the regular glass. The study findings show that adding ECG system to courtyard reduces the energy consumption, therefore the building saves 25% of the energy in clear state, and when the system is tinted, it saves 57.5% of the energy, this applies to the summer season. While in the case of winter, the ECG system is efficient in energy consumption with heating, the building saves 80% of energy consumption, which reduces the cost. The study concludes that the number of years needed to recover the price of ECG system is 7.8 years which means that the courtyard is a sustainable solution in residential design according to Revit Program and Enterprise Green Communities (EGC) standard.

Keywords: Courtyard, Electrochromic Glazing System (ECG), Revit program, Amman city.

Cite this article: Shireen M. Al-Saleh and Wael W. Al- Azhari Reviving Courtyard Concept Using Electrochromic Glazing System In Residential Building - The Case Of Amman City International Journal of Civil Engineering and Technology
Reviving Courtyard Concept Using Electrochromic Glazing System in Residential Building - The Case of Amman City

(IJCIET).10(2),pp; http://www.iaeme.com/ijciet/issues.asp?JType=IJCIET&VType=10&IType=02

1. INTRODUCTION

The courtyard dwelling is one of the most imperishable architectural forms, overriding historical cultural and regional boundaries. Its balance of a straightforward and a simple appropriate construction, social, environmental control and familial structures keep to engage architectural historians and architects. Historically, courtyard house has been subjoined to building for different functions, in the architecture of the Arab world, most dwellings contain courtyard house and the main function of the courtyard house is its positive thermal effect on the surrounding living spaces. The courtyard dwelling remains an appropriate form and shape, not only for Arab and Islamic culture but also for the environmental conditions of Mediterranean territories. It could offset the requirements of contemporaneous lifestyles, if it considered and redefined in the socio-economic and new of technological changes. Looking at the countries past; utilize of passive techniques like the courtyard is prevailing in its architecture. That methods were needful for keeping agreeable, helpful and convenient environments through inciting stack impact, particularly in the hotter months. Unfortunately, with a presentation of air conditioning and the openness to oil, these components gradually vanished. For the present, they are the topic of vernacular architecture design research of the national area and consider as the quintessence of sustainability. This examination is a push to restore or recapture the utilization of courtyard in an advanced setting in a modernistic context, which was customarily known for its uncommon passive cooling performance, and to advance vitality powerful structure in Mediterranean climates by inserting a simplified thermal model utilizing the application of Electrochromic Glazing (ECG) system as an alternative cover to conventional glazing cover in courtyard within the climate of Jordan using the Revit-energy modeling software. There are many researches associating courtyard-dwelling form with social and design theories, focusing on discussions of architectural form and history and associating courtyard-dwelling form with thermal mass. But there are few researches revive courtyard-dwelling form with new technology that rises as many questions that need to be answered in this area, i.e. how can the new technologies revive the courtyard? The exploration utilizes ECG system inside the climatic conditions of Amman city to prove higher total yearly energy saving potential for courtyard.

2. METHODOLOGY

To achieve the new courtyard concept the research defines a methodology that divided into two approaches, which are: The First one is a descriptive approach with an analytical method that studies the new technologies of the ECG system. The second approach is an empirical one that supports the main hypothesis of the research this is done through: An evaluation of the energy benefits that may emerge from introducing ECG system rather than traditional glass over the courtyard in Amman city buildings.

The vitality advantage of ECG framework is evaluated as far as its capacity to diminish the general vitality utilization "from building framework, for example, Heating, Ventilating, and Air Conditioning (HVAC) and electrical lighting on a yearly base through giving controlled sunshine condition when contrasted with standard coating.

The energy advantage of ECG system is evaluated as far as its capacity to diminish the general energy consumption "from building system for example, Heating, Ventilating, and Air Conditioning (HVAC) and electrical lighting on a yearly base through giving controlled day light environment when contrasted with standard glazing.

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The Revit energy modeling software is utilized to assess the energy consumption and energy performance, fundamentally the reductions in lighting and (HVAC).

2.1. The Electrochromic Glazing System

“The ECG system is a new type of technologies called smart window, dynamic glazing or switchable glazing, it can convert transparency in response to outer changes, and its energy reduction potential can be achieved through control of daylight, glare and solar heat”, (Granqvist, et al., 2009) [1].

EC Glass that features a chemical composition that has the ability to change color when a charge of electricity is applied, allowing a person to control when a window is tinted or translucent.

This feature allows for optimal day lighting with the option of controlling glare or harsh direct light, (Wadah, H., 2006) [2]. Out of these various types Figure (1), the Electrochromic windows provide the greatest versatility and thus the greatest potential in energy savings for window applications, (Mäkitalo, 2013) [3]; And out of all the conventional smart glass technologies, ECG system (Electrochromic glass) is being known as one of the promising ones, owing to the greatest dynamic control, as it allows heat and light through the glass. With its unparalleled properties such as fastest switching times and durability, ECG System is expected to revolutionize the architectural application section occupying the pioneer chunk of market proceeds by 2020, (Premium market research reports, 2014) [4].

Table (1), displays the Center of Glass (COG) performance levels for ASHRAE 90.1-2007 code specified static glass per climate zone and Sage Glass performance for both clear and tinted states utilized in the eQuest energy modeling, (the Sage Glass Energy Performance Modeling report, 2010).

Table 1

<table>
<thead>
<tr>
<th>Climate Zone</th>
<th>COG (C)</th>
<th>Sage Glass (E)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone A</td>
<td>0.50</td>
<td>0.55</td>
</tr>
<tr>
<td>Zone B</td>
<td>0.55</td>
<td>0.60</td>
</tr>
<tr>
<td>Zone C</td>
<td>0.60</td>
<td>0.65</td>
</tr>
<tr>
<td>Zone D</td>
<td>0.65</td>
<td>0.70</td>
</tr>
</tbody>
</table>

Figure 1: shows the type of smart glass.

Source: (Granqvist, et al., 2009) [1].
Table 1: Glazing performance per ASHRAE 90.1-2007 and actual Sage Glass characteristics

<table>
<thead>
<tr>
<th>Type</th>
<th>Thickness</th>
<th>SHGC</th>
<th>U-Value</th>
<th>VLT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sage Glass Double Pane (Argon)</td>
<td>Clear</td>
<td>0.48</td>
<td>0.29</td>
<td>62%</td>
</tr>
<tr>
<td></td>
<td>Tinted</td>
<td>0.09</td>
<td>0.29</td>
<td>3.5%</td>
</tr>
<tr>
<td>Sage Glass Triple Pane (Argon)</td>
<td>Clear</td>
<td>0.38</td>
<td>0.14</td>
<td>52%</td>
</tr>
<tr>
<td></td>
<td>Tinted</td>
<td>0.05</td>
<td>0.14</td>
<td>2.9%</td>
</tr>
</tbody>
</table>

Source: (Sage Glass Energy Performance Modeling, 2010) [5].

2.2. How Electrochromic Glazing (ECG) System Works?
There are several types of ECG systems and there are various ways to achieve the electrochromic capability; this strategy relies upon transitional metal oxides, a standout amongst the most widely recognized one and all the more notable is metal oxide EC, for example, tungsten. Tungsten trioxide (WO3) is well recognized for its good EC stability and properties, Figure (2), displays the arrangement which is a five-layer, Tungsten trioxide (WO3) coating sandwiched between dual glass panes.

“This technology, ECG system, works by passing a low-voltage electric current across a microscopically-thin coating on the glass surface.

When a voltage is applied to the transparent conductive oxide layers in the device, ions (lithium and hydrogen) move into the tungsten trioxide layer, the combination of which produces a blue tint, if the voltage is reversed the ions move back to the counter-electrode and the window is bleached” (Katanbafnasab and Abu-Hijleh 2013) [6].

![Figure 2: Layers of EC glazing and the working mechanism.](image)


2.3. The Thesis Case Study and Simulation Process
In this section, the researcher summarizes the results of a simple energy modeling exercise conducted to assess the impact of Electrochromic glazing (ECG) system might have in the applications of residential courtyards; by surveying the energy benefits that may emerge from introducing ECG system rather than regular glass over the courtyard in Aldyrania House, in Amman city.

Evaluated regarding its capacity to limit the entire vitality utilization from building frameworks, for example, Heating, Ventilating, and Air Conditioning, (HVAC) in addition to
electrical lighting on a yearly premise amid giving controlled sunshine condition when contrasted with regular coating. The energy advantage of ECG system will be evaluated regarding its capacity to limit the entire whole energy consumption from building systems such as Heating, Ventilating, and Air Conditioning, (HVAC)) in addition to electrical lighting on a yearly premise during giving controlled day light environment when contrasted with regular glazing.

A significant part of integrating ECG system technology into future courtyard dwelling projects is to create the courtyard more sustainability, by utilizing the Revit simulation software. The Revit software is used to evaluate the energy performance, and gauge fundamentally the decreases in lighting and (HVAC) breaking down the measurements of energy before and after adding the Electrochromic glazing system, in three states, the first with conventional glazing, the second by using ECG system in the clear state, the third by using ECG system in the tinted state

2.4. The Selected Case Study– Aldyrania House Analysis.

Aldyrania house, is a one-story building of an area of 408 m² with conventional plan, see Figure (3), and the building has a total window area of 21 % of the facades. See Table (2). The analysis of the house is done by Revit software, each zone area is represented as an individual zone in a plan in this analysis, see Figure (4) and Figure (5). Parameters, such as daylight illuminance and temperature, are calculated on a zone to zone basis during simulation, see Figure (4); the climate used for the energy usage simulations is for the Amman area in Jordan.

![Figure (3): Aldyrania house exterior by Rivet 2016 source: (researchers, 2017).](image)

<table>
<thead>
<tr>
<th>Table (2): Basic data of the house Source: (researchers, 2017) by Revit, 2016.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Location:</strong></td>
</tr>
<tr>
<td><strong>Weather Station:</strong></td>
</tr>
<tr>
<td><strong>Outdoor Temperature:</strong></td>
</tr>
<tr>
<td><strong>Floor Area:</strong></td>
</tr>
<tr>
<td><strong>Exterior Wall Area:</strong></td>
</tr>
<tr>
<td><strong>Average Lighting Power:</strong></td>
</tr>
<tr>
<td><strong>People:</strong></td>
</tr>
<tr>
<td><strong>Exterior Window Ratio:</strong></td>
</tr>
<tr>
<td><strong>Electrical Cost:</strong></td>
</tr>
<tr>
<td><strong>Fuel Cost:</strong></td>
</tr>
</tbody>
</table>
Reviving Courtyard Concept Using Electrochromic Glazing System in Residential Building - The Case of Amman City

Figure 4: Ground Floor Plan with zoning - Aldyrania house
Source: (researchers, 2017) by Revit, 2016

Figure 5: Detail drawing of the courtyard - Aldyrania house. Source: (researchers, 2017) by Revit, 2016

2.5. Data Analysis
This section analyzes the total energy building with ECG system on three cases by using simulation Revit tool, it consists of three parts, the first part calculates and compares the annual energy use and cost for the three cases, the second part calculates the life cycle energy use and cost for the three cases and the third part calculates then compares the heating and cooling loads use and cost for the three cases.
2.6. Simulation Tool

Revit programming is an inclusive sustainable device which investigations a building’s design from concept to detail, and Rivet Analysis gives a decent variety of examination, analysis, reenactments and simulations of building energy usefulness and functionality which can enhance performance of an investigation building.

The Revit software was selected for this research as it is widely utilized as an industry standard when simulating building energy characteristics and indoor climate, Revit works with various zones inside the building in which the occupant can specify parameters of components. Significant parameters when implementing ECG system in Revit are the glazing performance parameters and the periods within which the ECG system can operate.

The ECG system window parameters and performance data are presented in the previous section, Table (1). It is capable to communicate and analyze with other tools to receive preferable outcomes within the context of a specific building environment, Revit capabilities in analyzing Aldyrania house are as follow:

2.7. Building Energy Analysis

The author used energy modeling to assess the potential impact of installing ECG system in a single-family house and utilized the Revit software to analyze and develop a single-family house model (Aldyrania house), general characteristics of the model is shown in the previous section. Total building energy analysis — calculate whole energy of building with ECG system on three cases of the building which is:

1. In the case of applied conventional glass on the building (normal state).
2. In the case of applied the ECG system on the building (clear state).
3. In the case of applied the ECG system on the building (tinted state).

2.8. Annual Energy Use/Cost

This part calculates and compares the annual energy use and cost for the three cases, (A) normal, (B) clear, and (C) tinted.

2.8.1 The First Case:

the cost of energy used in the building with the conventional glass, see Figure (6) and Figure (7) =

The price of energy cost per square meter during the year × area of the building

Where …

The price equals 6.289$ as was estimated by Revit, see Figure (6).

The area of Aldyrania house is 408 m²

Thus, the cost of energy used in the building in this case = 6.289$×408m² = 2565.9$.
Reviving Courtyard Concept Using Electrochromic Glazing System in Residential Building - The Case of Amman City

Figure 6: Annual Energy Use/Cost, Case one (conventional glass)  
Source: (researchers, 2017) by Revit, 2016

Figure 7: detail Annual Energy Use/A. fuel (left) – B. electricity (right), Case one (conventional glass)  
Source: (researchers, 2017) by Revit, 2016

2.8.2. The Second Case:
the cost of energy used in the building with the electrochromic glazing ECG system, in the clear state, Figure (8) and Figure (9) =
The price of energy cost per square meter during the year × area of the building =
Where …
The price equals 5.329$ as was estimated by Revit, see Figure (8).
The area of Aldyrania house is 408 m²
Thus, the cost of energy used in the building in this case = 5.329$×408m² = 2174.2 $.
2.8.3. The Third Case:

the cost of energy used in the building with the electrochromic glazing (ECG) system, in the
tinted state, Figure (10) and Figure (11) =

The price of energy cost per square meter during the year × area of the building =

Where …

The price equals 4.194$ as was estimated by Revit, see Figure (10).

The area of Aldyrania house is 408 m²

Thus, the cost of energy used in the building in this case = 4.194$\times408\text{m}^2 = 1711.2$.

Figure 8: Annual Energy Use/Cost, Case two (clear state) Source: (researchers, 2017) by Revit, 2016

Figure 9: detail Annual Energy Use/A. fuel (left) – B. electricity (right), Case two (clear state)
Source: (researchers, 2017) by Revit, 2016
Reviving Courtyard Concept Using Electrochromic Glazing System in Residential Building - The Case of Amman City

Figure 9: detail Annual Energy Use/A. fuel (left) – B. electricity (right), Case two (clear state)
Source: (researchers, 2017) by Revit, 2016

The average cost of energy used in the building with the Electrochromic Glazing (ECG) System= (the second case (clear) cost + the third case (tinted) cost) / 2
= (2174.2 +1711.2)/2=1943$.

To calculate the amount of savings in the bill for the building energy consumption, see Table (3) =
(Amount of consumption in the case of conventional glass) - (consumption Amount after application the ECG system) = 2565.9$ -1943$ = 622.9 $.

Table (3): Annual Energy Use Intensity and cost

<table>
<thead>
<tr>
<th>Site</th>
<th>Case</th>
<th>Electricity (EUI)</th>
<th>Fuel (EUI)</th>
<th>Total (EUI)</th>
<th>The cost of energy ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amman</td>
<td>Conventional glass</td>
<td>109</td>
<td>348</td>
<td>740</td>
<td>2565.9</td>
</tr>
<tr>
<td></td>
<td>ECG system - clear state</td>
<td>93</td>
<td>260</td>
<td>593</td>
<td>2174.2</td>
</tr>
<tr>
<td></td>
<td>ECG system - tinted state</td>
<td>72</td>
<td>253</td>
<td>514</td>
<td>1711.2</td>
</tr>
</tbody>
</table>

* EUI: Energy Use Intensity
Source: (researchers, 2017) by Revit, 2016

2.9. Life Cycle Energy Use/ Cost

This part calculates the Life Cycle Energy Use and Cost for the three cases.

To calculate the price of the Electrochromic glass material that is used in the building:
Every one-meter square (m²) costs 100$. (Lee and DiBartolomeo, 2000).

On the other hand, Life cycle energy use and cost was estimated by Rivet and the results were summarized in Table (4) that is shown below.
Table (4): Life cycle energy use/cost

<table>
<thead>
<tr>
<th>Site</th>
<th>Case</th>
<th>Life cycle electricity use</th>
<th>Life cycle fuel use</th>
<th>Life cycle energy cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amman</td>
<td>Conventional glass</td>
<td>1,330,619 KWH</td>
<td>4,255,482 MJ</td>
<td>85,658$</td>
</tr>
<tr>
<td></td>
<td>ECG system - clear state</td>
<td>1,131,656 KWH</td>
<td>3,180,714 MJ</td>
<td>72,576$</td>
</tr>
<tr>
<td></td>
<td>ECG system-tinted state</td>
<td>884,777 KWH</td>
<td>3,098,505 MJ</td>
<td>57.125$</td>
</tr>
</tbody>
</table>

This means that:
* (Life cycle energy cost of Conventional glazing for 30 years) – (Life cycle energy cost of ECG (taking average of clear and tinted states) for 30 years) =
  =85,658$ - (72,576$+57,125$) / 2 = 85,658$ – 64,850$ = 20,808$
* Thus, the value of energy savings for 30 years = 20,808$
* So, The value of energy savings for one year = 20,808$/30 = 693.6$.
About the price of the ECG system installation it equals:
(The total area where ECG system has been applied, which is the courtyard roof in [m²]) * (the price of unit area [$/m²])
= 54.16 m² (see Figure 9) * 100 $/m² (Lee and DiBartolomeo, 2000) = 5416 $
*So, the price of the ECG system installation=5416$
*The number of years needed to recover the price of ECG system= the price of the ECG
*The payback period (Years) equals:
  Total system installation cost ($) / the value of energy savings for one year ($/Year)
=5416 ($) / 693.6 ($/Year) =7.8 Years.
So, the system is able to pay back the cost in 7.8 Years which is less that the Enterprise Green Communities (EGC) standard 8.9 years and proves to be a sustainable system.

3. HEATING AND COOLING LOADS USE/COST
This part calculates and compares the heating and cooling loads use and cost for the three cases.
To calculate the amount of energy that will be used for heating and cooling, the results graphs (the heating and cooling loads) are based on the back-end DOE-2 whole building energy simulations run by Autodesk green building studio, these graphs explain how much energy the building needs in order to heat and cool, and where the energy is used.

3.1. Monthly Heating Load
To calculate the amount of energy that will be used for heating, according to the previous factors, Figures (12), (13), and (14), show the amount of energy used for heating for the three cases, it is divided into two parts, upper one shows the heating gain (+) and lower one shows the heating loss (-).
When the heating gain is equal to the heating loss, the energy consumption is less.
In this study January month will be chosen, because this month will have the lowest temperature, thus, the heating load will be maximum and, in this condition, it will be feasible to determine how much ECG system is capable of saving energy consumption, so saving cost.
To calculate the heating gain of ECG system, the study has to focus on the factors that are related to glass material properties which will change the gain according to them. The factors that fulfill this criterion are two: window solar and window conductive, about the other factors mentioned above they will be unchanged in all states so there will be no effect for them on the case study of Aldyrania house.

To calculate the amount of energy in January before and after applying the ECG system as shown in Figures (12), (13), and (14), Where the Window Conductivity (represents temperature loss) will be with the Window solar (represents heating gain), see Table (5).

In the Figure (12), the amount of energy consumption with heating in January before applying the ECG system (case one):

Window conductivity (heating loss) - Window solar (heating gain) = Heating load

\[ 10000 \text{ MJ} - 5000 \text{ MJ} = 5000 \text{ MJ} \]

![Figure 12: Monthly Heating Load according to building factor, Case one (conventional glass)](image)

Source: (researchers, 2017) by Revit, 2016

Figure (13), the amount of energy consumption with heating in January after applying the ECG system in clear state (case two):

Window conductivity (heating loss) - Window solar (heating gain) = Heating load

\[ 5000 \text{ MJ} - 4000 \text{ MJ} = 1000 \text{ MJ} \]
Figure 13: Monthly Heating Load according to building factor, Case two (clear state)

Source: (researchers, 2017) by Revit, 2016

Figure (14), the amount of energy consumption with heating in January after applying the ECG system in tinted state (case three):

Window conductivity (heating loss) - Window solar (heating gain) = Heating load

\[
5000 \text{ MJ} - 4000 \text{ MJ} = 1000 \text{ MJ}
\]

Figure 14: Monthly Heating Load according to building factor, Case three (tinted state)

<table>
<thead>
<tr>
<th>Month</th>
<th>Case</th>
<th>Window conductivity (heating loss)</th>
<th>Window solar (heating gain)</th>
<th>Monthly heating load</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>Conventional glass</td>
<td>10000 MJ</td>
<td>5000 MJ</td>
<td>5000 MJ</td>
</tr>
<tr>
<td></td>
<td>ECG system - clear state</td>
<td>5000 MJ</td>
<td>4000 MJ</td>
<td>1000 MJ</td>
</tr>
<tr>
<td></td>
<td>ECG system-tinted state</td>
<td>5000 MJ</td>
<td>4000 MJ</td>
<td>1000 MJ</td>
</tr>
</tbody>
</table>

Source: (researchers, 2017) by Revit,

From the above Table (5). It is obvious that the ECG system is efficient in energy consumption with heating, as the building needs only to spend 20% of the energy consumption compared to conventional glass system which means in other words that the building will save
80% of energy consumption. Therefore, using the ECG system will gain more energy with a lower cost.

3.2. Monthly Cooling Load
In the cooling mode, in August, because it is the highest month in temperature degree in Amman city. Heating Gain is one of the most factors that affect the energy consumption for cooling. So, when the heating gain is bigger, we will need more energy for cooling, see figures (15), (16), and (17).

**Figure 15**: Monthly cooling Load according to building factor, Case one (conventional glass) Source: (researchers, 2017) by Revit, 2016

**Figure 16**: Monthly cooling Load, Case two (clear state) Source: (researchers, 2017) by Revit, 2016
Figure 17: Monthly cooling Load, Case three (tinted state) Source: (researchers, 2017) by Revit, 2016

Table (6): The cooling load in August before and after applying the ECG system

<table>
<thead>
<tr>
<th>Month</th>
<th>Case</th>
<th>Window Solar</th>
<th>Monthly Cooling Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>August</td>
<td>Conventional glass</td>
<td>20000 MJ</td>
<td>20000 MJ</td>
</tr>
<tr>
<td></td>
<td>ECG system - clear state</td>
<td>15000 MJ</td>
<td>15000 MJ</td>
</tr>
<tr>
<td></td>
<td>ECG system-tinted state</td>
<td>8500 MJ</td>
<td>8500 MJ</td>
</tr>
</tbody>
</table>

Source: (researchers, 2017) by Revit, 2016

The table above (6) shows that, when applying the ECG system, the building will save 25% of the energy in case clear state, and when the glass in tinted state, it will save 57.5% of the energy.

4. CONCLUSION

The researchers have presented an alternative design of courtyard by utilizing ECG System for the future, what the researcher suggest is the surprising level of flexibility within the armature of the traditional courtyard form.

The ECG system can provide the designer with more design flexibility and the ability to utilize more glass in the covering of the courtyard and the ECG systems represent simple and an elegant solution for the control of heat and light occurrence on the covering of the courtyard.

By applying ECG system as an alternative to regular glazing in the courtyard roof in the residential house, (Aldyrania) among the climate of Amman city using the Revit energy modeling software, the findings have illustrated that the predicted energy benefits from replacing conventional glass with ECG system have the following effects:

Adopting ECG system to conventional courtyard house is enhances it is efficiency of energy consumption

- Adopting ECG system for cooling in summer season saves 25 % and 57.5% of energy consumption, in clear state and tinted state respectively.
- Adopting ECG system is efficient as well in winter, the building saves 80% of energy consumption, in both clear and tinted states.
Reviving Courtyard Concept Using Electrochromic Glazing System in Residential Building - The Case of Amman City

- Adopting ECG system showed that the number of years needed to recoup the price of ECG system is 7.8 years which means the courtyard is a sustainable idea according to Enterprise Green Communities (EGC) standard.
- Saving expenses; as the analysis suggests that the amount of annual savings in the electricity bill for the energy consumption for a whole-house equals 622.9 $/m² when using the ECG system and this indicates ECG is a competitive system at a price of approximately 100 $/m², within ten years.
- Reducing the annual energy consumption significantly in a residential building located in Amman city in Jordan as shown by the results.

A sustainability of the courtyard by using ECG System would confirm the central proposition of this research, thus the courtyard house is a model of low-energy design and is a unit which creates the essential building blocks for the making of sustainable designs.

5. RECOMMENDATIONS
From the results of this research the researchers recommend the following:
- Using this approach in residential buildings can help the investors to reduce the costs for the building and energy.
- Suggesting future work to further assess the potential impact of ECG System in residential applications includes:
  ➢ Additional modeling for the single apartment scale or/and for urban scale
  ➢ Additional climates examples in other cities either in Jordan or other countries in the Middle East.
  ➢ Compare performance to different orientation or areas of the courtyard.

REFERENCE