Title: **Assessment of Solar Energy Conversion Technologies-Application of Thermoelectric Devices in Retrofit an Office Building**

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ABSTRACT

Thermo electric (TE) devices offer an opportunity to introduce renewable energy into existing and new buildings. TE devices harvest energy from the temperature differential between the hot and cold side of a semiconductor material. In this study, the feasibility of integration of TE devices using the model of a generic enclosure will be explored. Some of these applications will involve the use of these devices as heat exchangers. However, these devices will be examined for their use in harvesting energy to provide the electric service for an office. Since demanded energy for some electronic devices can be generated directly, provided energy has the potential to take those loads off from the distribution. Besides, generated electricity expected to be replaced a greater amount of grid electricity for the periods when TE is generating. This paper represents a critical step for performing an analysis of using the proposed TE system in an office.

INTRODUCTION

There is no doubt that climate change is a real phenomenon that significantly affects human life today and will continue to do so in the centuries to come. Many of the reasons for climate change have been attributed to human activities. Construction and operation of buildings using nonrenewable energy contributes to the CO2 in the atmosphere. The increases in CO2 then contribute to climate change. Further, nonrenewable energy sources are not reliable over the long term; they are diminishing and cannot be replenished in a short period of time. Extraction of nonrenewable sources is becoming more difficult with increased adverse effects on the environment. Designing and constructing buildings with low-energy requirements that can be operated by renewable energy is becoming a necessity for architects and society.

Thermo electric (TE) devices offer an opportunity to introduce renewable energy into existing and new buildings. TE devices harvest energy from the temperature differential between the hot and cold side of a semiconductor material -- a phenomena described by Seebeck in 1821. The application of this effect was not common until the end of the 20^{th} century. The advent of semiconductor materials has resulted in the production of TE devices used in a wide variety of applications.

TE devices seem to have promising applications for integration into building systems and furnishings. Some of these applications will involve the use of these devices as heat exchangers. In this study these devices will be examined for their use in harvesting energy to provide the electric service for a typical university office. “Off the shelf” TE devices will be assembled in ways that will harvest energy resulting from naturally occurring temperature differentials in the built environment. The demand on the electric grid will be further reduced by using efficient, low voltage lighting within the office. Hence, little or no fossil energy sources would be required to provide electricity for the buildings or other enclosures. We anticipate that this feature will result in important long-term environmental benefits.

Since low-voltage lighting and demanded energy for some electronic devices (PCs and other related equipment) can be generated directly. Provided renewable energy has the potential to take those loads off from the distribution. Besides, we expect generated electricity to replace a greater amount of grid electricity for the periods when TE is generating. Further, Office equipments have the potential to store excess amount of energy provided in their battery.

<u>Thermoelectric Power Generators</u>

Thermoelectric devices (TE) have two possible uses heat exchange purposes and secondly can be used for electrical generation. That using them as heat exchanger also has the potential for reducing the demand on electric energy and buildings. However, this study is focusing on energy harvesting by using them as power generators.

Heaters and coolers are solid-state devices that convert electricity directly to temperature differentials. The concept of solid-state refrigeration dates back to 1834. The Peltier effect is the principle at work behind thermoelectric coolers or heaters. As shown in the Fig. 1 these devices can be integrated with PV. The electricity generated by the photovoltaic panel can be passed through these devices and provide two surfaces with different temperature which can be conducted with fluids through the building to provide heating and cooling loads.

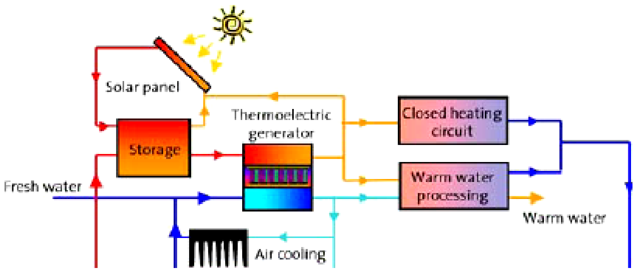


Figure 1. Schematic integration of PV with TE Voltage provided by PV would be transformed to heat in the heat exchanger.
From: http://www.science.doe.gov/grants/FAPN06-15.html
Retrievd: 10 April 2008.

Another class of thermoelectric devices converts heat that provided by different temperature directly into electricity, this phenomenon was discovered in 1821 and is called ‘‘Seebeck effect’’. The Peltier and Seebeck effects are reversible. Thermoelectric devices have small size and are light in weight. They are friendly to the environment as CFC gas or any other refrigerant gas is not used. Due to these advantages, the thermoelectric devices have found a large range of applications in cooling electronic devices, powering remote facilities, etc; however, those devices have received little examination for their use and harvesting energy for existing buildings.

In the process of analyzing the overall TE system, we first focus our attention on each unit in detail. In this paper, we present the design and analysis of the TE unit for the wall system. Specifically, this study develops a model of the TE unit.

Here, the individual models of the components of the TE unit are coupled, yielding a single integrated model that takes into account the effect of the heat sink on the TE system. When a temperature differential is established between the hot and cold ends of the semiconductor material, a voltage is generated. This voltage is called the Seebeck voltage, and it is directly proportional to the temperature differential. As shown in Fig. 2, if heat supplied at the one junction causes an electric current to flow in the circuit and electrical power is delivered. In practice a large number of such thermocouples are connected electrically in series to form a ‘‘module’’. More than one pair of semiconductors are usually assembled together to form a thermoelectric device (module).

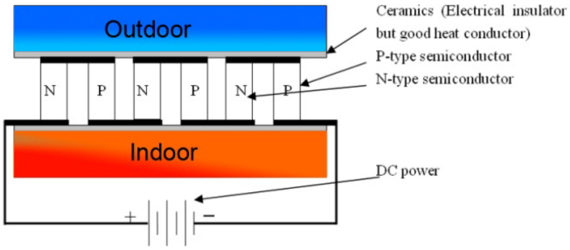


Figure 2-Schematic of a single-stage thermoelectric module
From: http://www.customthermoelectric.com/
Retrievd: 12 April 2008.

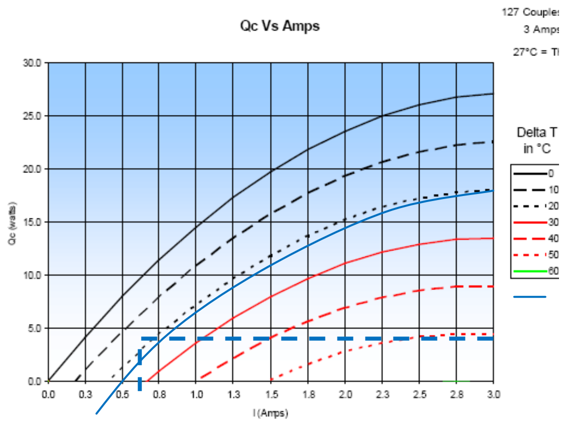
The voltage created is of the order of several microvolts per degree difference. In the circuit:
The voltage developed can be derived from:

$$V = \int_{T_1}^{T_2} (S_B(T) - S_A(T))\, dT$$

S_A and S_B are the Seeback coefficients (also called thermoelectric power or thermopower) of the metals A and B, and T_1 and T_2 are the temperatures of the two junctions. The Seebeck coefficients are non-linear, and depend on the conductors' absolute temperature, material, and molecular structure. If the Seebeck coefficients are effectively constant for the measured temperature range, the above formula can be approximated as [11]:

$$V = (S_B - S_A) \cdot (T_2 - T_1)$$

Conventional thermoelectric devices have various specifications for various applications; the dimensions vary from 3 mm square by 4 mm thick to 60 mm square by 5 mm thick, the maximum power generation rate from 0 to 10 Amps. The maximum temperature difference between the hot and cold side can reach from 10 to 70℃ . According to Fig. 3, by introducing 60℃ temperature difference between two surface of the 127 couples, the electricity generated in the TE devices is 3 amps. However, itis more likely to have 18℃ degree differential between interior and exterior of the office during summer and winter time in the studied site. Therefore, the power generation reached to 1.2 amps



for each module in average as projected in the Fig 3.
Figure 3. Relation between delta T and Current (amps)
From:http://www.customthermoelectric.com/tecs/pdf/12711-9L31-03CL_spec_sht.pdf
Retrieved 13 April, 2008.

The governing equations are as follows:

$$Q = A((T_O - T_I)(L/K + 1/h))$$

Where;

Q is the heat lost or gained in watts
L is the thickness of insulation in meters (m)
K is the Thermal Conductivity of the insulation material in watts/meter℃
A is the outside surface area of the container in meters squared (m^2).
h is the Heat Transfer Coefficient of the surface material in watts/meter^2℃
T_O is the Outside temperature in ℃C
T_I is the Inside temperature in ℃ C

And, Q=E x I
Where;
Q (Power) is in watt and E (voltage) is in volts and I (current) is in amps.

A typical thermoelectric device is composed of two ceramic substrates that serve as a foundation and electrical insulation for P-type and N-type thermoelements that are connected electrically in series and thermally in parallel between the ceramics.

The main components of the TE devices are an air gap, a copper plate, thermoelectric modules and a rectangular fin heat sink (Fig. 4).The incident solar radiation heats the copper plate to create a temperature difference between the TE modules(summer mode), which subsequently can generate a direct current. Multiple semi-conductors are assembled to manufacture a device and multiple of manufactured TE devices assembled to retrofit a room (Fig.5). The provided current can be stored in a battery and can run the low voltage lighting, PCs, and related equipment (Fig. 6)

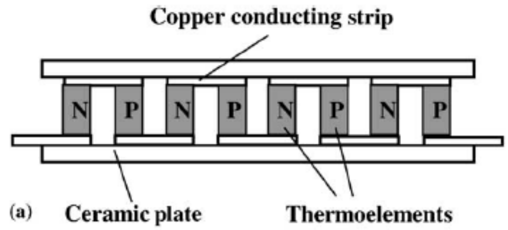


Figure 4. Schematic diagrams of multicouple thermoelectric modules. Configuration with ceramic insulating plates and large inter thermo element separation for the individual modules

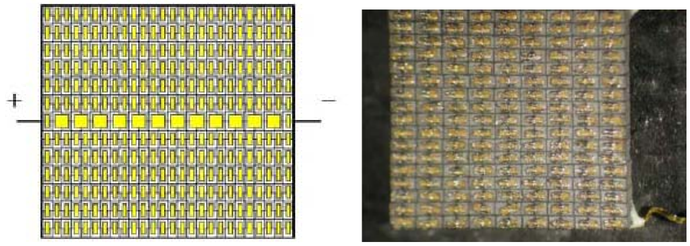


Figure5. Multi thermoelectric devices. 0.142 inch thick slice of the 5 Watts module produces 0.6amps at Δ T 18℃ .

According to commercial modules, 90 devices to generate demanded energy (refer to section Estimation of Renewable Energy of this paper) expected to be needed. That these numbers can really retrofit the office is options to be explored. In the initial design 90 devices work together and the results will be monitored. Fig.4 show schematic diagrams regarding how the commercial modules will be assembled into a system to provide renewable energy at the room scale.

Summary of advantages for renewable energy

The thermoelectric devices offer several distinct advantages over other technologies:

• Thermoelectric devices have no moving parts and, therefore, need substantially less maintenance.
•Life testing has shown the capability of thermoelectric devices to exceed 100,000 h of steady state operation.
•Thermoelectric devices contain no chlorofluorocarbons or other materials that may require periodic replenishment.

•Thermoelectric devices are not position-dependent.

The longevity of thermoelectric devices is excellent and usually superior to that of PV devices due to the absence of any moving parts [8] . These devices are easy to replace and each of the devices is $10-$40.

RESEARCH OBJECTIVE

The objective of this study is to propose how to supply the electrical needs of an office by energy harvesting with TE devices.

The simulation results of these devices indicated that the thermoelectric generator offered attractive performance features as primary or auxiliary power source for low voltage lighting and equipments that can be operated by (Riffat et al., 2003).

This study is trying to examine if these thermoelectric module meets the requirements to retrofit an office building. Indeed, TE system is a new technology in the building sector and need to be verified in order to be used as a tried-and-true technology. This study proposes to combine thermoelectric generator devices on the window of a building to produce the electricity by using the difference of temperature between cold and hot side of the outdoor and indoor space respectively.

The project will be located in typical office on the south side of the Architecture Building at UIUC campus. The office will be approximately 150 SF with typical electric loads of lighting, PC(s), monitor, printer, and scanner. There are several reasons for choosing this site. Firstly, there are large numbers of old buildings on campus that this approach can be introduced to them as well. Secondly, Architecture building's offices are small separate rooms so it can be retrofitted individually, in other word, since they are not open space, they can be dealt with in individual basis. Thirdly, since this office is located in architecture building, it will provide an opportunity for students to observe and learn about renewable energy. This is an office which architecture students can visit it during the monitoring time as a lab.

<u>**Similar projects at other campuses**</u>

This study will be the premier project which is exploring the harvesting energy provided by TE devices. There are no similar projects at other campuses. This innovative harvesting energy will provide opportunity to explore the efficiency and viability of TE devices as power generators.

This study intended to design a TE power generation modules to retrofit a low voltage office and explore the options of expanding this approach for other offices on campus.

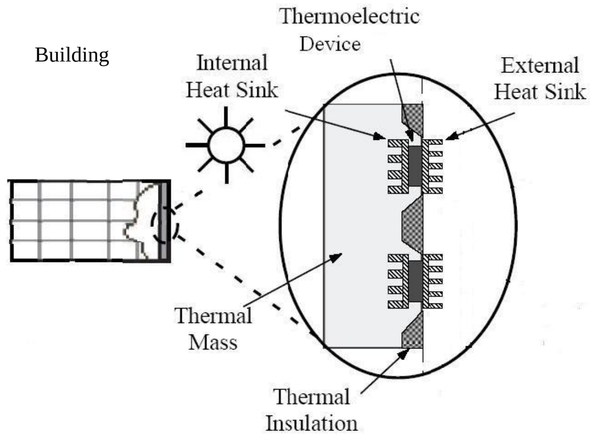
METHOD

<u>**Basic model for TE system**</u>

This section provides a brief description of the proposed system (see Fig. 5). As shown in Fig. 5, the system consists of modules of a thermoelectric (TE) system. TE Systems are devices that convert the differential temperature between inside and outside to electrical energy. The TE units are dispersed inside the openings that are provided in the insulating layer. Each TE unit consists of two heat sinks. As shown in Fig. 5, the internal and external heat sink either absorbs or dissipates heat according to the season of the year whether outside is warm or cold.

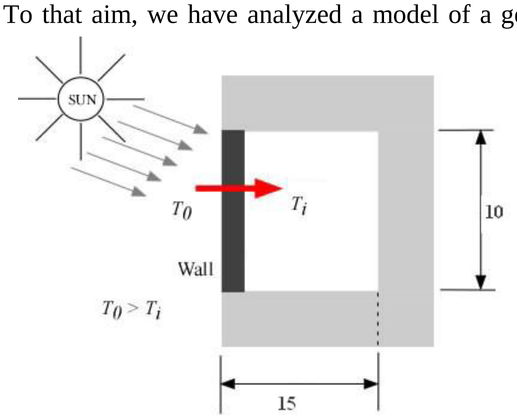
Figure 5. Schematic diagrams of thermoelectric system integrated in building [4]

To explore the feasibility of the TE system, a



preliminary feasibility analysis was performed on a model of a generic enclosure. The next section summarizes this feasibility analysis.

To that aim, we have analyzed a model of a generic



enclosure that has dimensions of 15ftx10ftx10 ft.

Figure 6. Schematic of an office enclosure with TE wall.

Estimation of Electrical Load for an Office Enclosure

To demonstrate the application of the TE unit, we analyze the model of a 10 ft · 10ft · 15ft of office enclosure. This section provides the assumptions made in this design study, and the estimation of the operating loads for this enclosure. Fig. 5 schematically represents the generic enclosure for which the TE unit is designed.

Assumptions

The following assumptions were made for the preliminary feasibility analysis. (1) Thickness of the wall, *t* = 0.5 ft, (2) Only one of the four sidewalls acts as TE wall, and heat losses or gains from all other walls are negligible, (3) °F °C °F °C according to the climatic studies the average difference temperature between inside and outside during six months of the year is 18°C , in this study, a summer day has been assumed that The external temperature is 100°F (*T0* = 38°C) and the internal temperature is 68°F (*Tc* = 20°C) during 8 hours of day (4) Conduction heat transfer through wall is the only mode of heat transfer, (5) All the thermoelectric modules absorb equal amounts of heat, (6) The area of the TE devices is equal to that of the TE wall (10x10ft), and (7) TE units are connected in a parallel circuit. Each TE is 1.18in x 1.18 in.

RESULTS

Estimating Office Loads

This project creates renewable energy to retrofit an office approximately 150 SF. To light this space, we need 2-4 low voltage lighting fixtures for office tasks. As well as 19 volts 3 amps needs to supply notebook, and 24 volts 1.1 amps for scanner. In general, to provide the amount of retrofitting energy for this office, we need 57Watts for notebook, 24.1 watts for scanner and 64-128 for lighting, and 127 Watts for printer. We scheduled office for 8 hours a day.. The estimated power needed to retrofit the office is 0.435 KW per hour.

To compensate this load, we selected 127cpl/0.4A type TE units manufactured by Custom Thermoelectric Inc. Each (0.4 amp, 8.3volt, 5 watt modules at $30 each) type TE unit consists of 127 thermocouples [9]. The climatic data of pertinent site(refer to table2), shows that almost during six month of the year, the average temperature difference between inside and outside is at least 18°C. To provide the estimated energy(0.435KW per hour) 90 cells will be needed. The produced energy can compensate for half of the year with this system which average temperature difference 18 °C between inside and outside.

Table 1. provides the results of this preliminary feasibility study.

# TE (n)	Current *I out* (Amp)	Voltage *V* (Volts)	Power *Each TE* (Watts)	Temperature difference	Total Power *Ptotal* (Watts)	COP of the TE Units
90	0.6	8.3	5	18	450	0.86

Design variables:

The number of TE (N) and the temperature difference (To-Ti) are the two design variables for the TE system. During the design process, the number of TE devices is not allowed to become less than what we need to retrofit the office; and no upper limit is provided for the number of TE except the area of the wall which these devices are mounted. The wall area is sufficient for 90 of TE devices.The TE devices are selected from the product catalog [9]. The current (I) is not allowed to exceed the maximum allowable current (Imax) for the battery to store the extra voltage, which is specified in the product catalog as well.

The upper and the lower bounds imposed on the temperature difference are given in the Fig. 3.

Estimation of Renewable Energy

a. Estimation of electrical load for office enclosure:

As shown in Table 1, the amount of energy needed to operate an office 10ft x 10ft x 15ft is 435 watts per hour. Each of these devices provides 5watts per hour in case DT is 18°C C; therefore, we need 90 of TE devices to retrofit the office. Besides, we have to consider 2 different modes that provide this differential temperature:

Winter mode: Outside is cold and inside is warm.
Summer mode: Outside is warm and inside is cold.

Table 2. Average mean temperature Champaign from: www.sws.uiuc.edu/atmos/statecli/cuweather/2001/an n2001.pdf Retrieved: 18 Oct.2008

Month	Average mean Temperature(°F)	Average Δ T Indoor and outdoor
Jan	-3.61	22-(-3.61)=25.6
Feb	-0.8	22-(-0.8)=22.8
March	2.7	22-2.7=19.3
Apr	14.4	7.6
May	17.8	22-17.8=4.2
Jun	28	28-20=8
Jul	38.2	38.2-20=18.2
Aug	37.7	37.7-20=17.7
Sep	18.2	22-18.2=3.8
Oct	11.6	22-11.6=10.4
Nov	9.4	22-9.4=12.6
Dec	1.6	22-1.6=20.4

b. the significant energy inputs:

At this scale, the input energy is not significant. The energy inputs reflected in cost, since the only energy inputs is shipping cost. The other energy input is solar which is totally free.

c. the net amount of clean energy created

All the energy created by this system is clean.

Environmental Impact

This project will remove part of the electricity load from distribution. Indeed, generated energy by these devices is clean and has no negative impact on environment. It has to be mentioned that if this project scale up to all of the rooms in architecture building, savings and impacts is going to be significant. The amount of energy needed to operate an office 10 x 15 is 2000KW annually for regular office according to 90.1-2004 User's manual ANSI/AHRAE/IESNA Standard 90.1-2004 energy standard for building. Since this project is going to use low voltage lighting and use DC directly for the office equipments, Retrofit of the office is expected to need less energy which is mentioned above.

At this subsection the amount of green house gases reduction by the offset use of fossil fuel energy sources normally used by the university would be calculated. It should be mentioned that all the numbers related to annual energy savings and less gas emissions are provided by university [12].

Annually Savings: .435 kW * $.072/kWh *4380 hrs/yr = $274

Less CO_2 emission: 1.936 lbs CO_2 /kWh * .435 kw * 4380 hrs/yr =**7377.32 lbs/yr**

Less NO_x emission: .00191 lbs NO_x /kwh * .435 kw * 4380 hrs/yr =**7.2782 lbs/yr**

Less SO_x emission: .00635 lbs SO_x /kwh * .435 kw * 4380 hrs/yr =**24.19731 lbs/yr**

CONCLUSION

Thermoelectric technology has been used practically in wide areas recently. Thermoelectric power generative devices are attractive technologies that not only can serve the needs for refrigeration, air-conditioning applications and power generation, but also can meet demand for energy conservation and environment protection. However, due to the low COP or low energy conversion efficiency of thermoelectric devices, currently the thermoelectric devices can only be used in limited applications, such as aerospace, military or cases in which the cost is not the main consideration. New thermoelectric materials with high thermoelectric performance, more modern collecting technology and transferring technology relating with solar energy, and more advanced optimization design of the thermoelectric devices providing power for buildings are being tremendously anticipated. In other word, energy costs and environmental regulations regarding the manufacture and release of CFCs has revived the interest in this area. However, significant lack of verified models in the domain of the proposed TE technology is felt.

The application of the proposed design strategy of TE system was demonstrated by designing a TE unit to retrofit an office enclosure.

The electrical load was estimated for the studied enclosure. The results indicate that the total output power required operating the office increases as the distribution of differential temperature increases. Based on the assumptions made in the study, the TE unit configuration involving 30 TE of (9.0 amp, 9.4 volt, 42 watt modules) type was found to be optimal for the office enclosure. This design represents a trade-off between the input temperature difference requirement and the number of TE devices used in the TE unit. This paper represents the first step in the development of a design approach for the practical implementation of TE systems. The next step would be study the accuracy of the studied model by comparing its results with those of a comprehensive model developed by producer. It should be noted that the TE technology is promising to generate electricity, even though it has not proven yet.

In recent years, it has been realized that in situations where the supply of heat is cheap or free, as in the case of differential temperature inside and outside or waste heat, efficiency of the thermoelectric generation system is not an overriding consideration.

The concept of waste-heat thermoelectric power generator offers many advantages; the most significant ones might concern its simplicity, reliability, and safety. The potential for using thermoelectric generator in buildings and increased market penetration is promising. The great extreme economic advantage to using thermoelectric devices to generate electricity from different temperature of outdoor, indoor, and waste heat on the surface of water pipe is therefore promising.

The prospects of the applications of thermoelectric devices

Any available heat source such as the surface of a water pipe in building would provide sufficient heat flux to these power applications.

Most of the recent research activities on applications of thermoelectric power generation have been directed towards utilization of industrial waste heat. The Japanese initiated a major waste heat recovery program. Waste heat costs very little or nothing. Therefore, where there is abundant waste heat, thermoelectric makes sense.

It is possible to utilize waste heat to power a thermoelectric such as the surface of a hot water pipe to provide different temperature. This application is another possibility to generate electricity in office building.

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