Chapter 15

Building-Integrated Thermoelectric Cooling-Photovoltaic (TEC-PV) Devices

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Additional information is available at the end of the chapter

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Abstract

Photovoltaic driven thermoelectric cooling devices are of great importance in terms of alternative cooling sustainable technologies. Depending on Peltier effect of the thermoelectric cooling (TEC), heating and cooling is achieved by applying a voltage difference in the thermoelectric module. Theoretical design considerations of building-integrated thermoelectric cooling-photovoltaic (TEC-PV) devices are analyzed. System design of a TEC-PV device is investigated with varying fresh outdoor ventilation rates. Integrated design with ceiling suspended, wall mounted, rooftop and active façade TEC-PV devices is considered in the analysis. The effect of voltage, air flow rate and height of fin heat transfer surface is also investigated. Expressions along with results for theoretical exergy of a TEC-PV device are also provided.

Keywords: thermoelectric cooling, TEC-PV device, HVAC, heat sink, solar energy, energy efficiency

1. Introduction

Thermoelectric module is a sold-state energy conversion device made up of thermocouples, which are wired in series electrical circuit and parallel thermal junctions. A thermocouple consists of N-type and P-type semi-conductor elements, so as to generate thermoelectric cooling (viz., Peltier-Seebeck effect) when a voltage difference in appropriate direction is applied through the connected circuit. Thermoelectric cooling has benefits of high reliability, no moving parts, compact size, no requirement of thermo-fluid and light weight of thermoelectric modules. The direct current (DC) required to power thermoelectric cooling (TEC) modules can be easily fed by solar powered photovoltaic (PV) devices. In this way energy conservation is achieved through utilization of available solar energy. With application of low voltage DC power source in a TEC module, heat transfer takes place from one side to the other side. In this way, TEC module's one side is cooled and other side is heated. In a TEC module, electric current drifts from N-type element to P-type element [1]. The temperature of the cold junction gradually decreases with heat transfer mechanism from environment to cold junction at a lower temperature. This heat transfer mechanism takes place with passing of transport electrons from a low energy level inside the P-type thermocouple element to a high energy level inside the N-type thermocouple element through the cold junction. Simultaneously, transport electrons transmit absorbed heat to hot junction at a higher temperature. This extra generated heat is dissipated to heat sink, whereas transport electrons return to a lower energy level in the P-type semiconductor element, viz., the Peltier effect takes place (see **Figure 1**).

There is constant development and efforts made for making thermoelectric air-conditioning systems in technical competence with vapor-compression technology. The performances of thermoelectric and conventional vapor compression air-conditioners have been compared by Riffat and Qiu [2]. Results have shown that the COPs of vapor compression and thermoelectric air-conditioners are in between 2.6–3.0 and 0.38–0.45, respectively. However, thermoelectric air conditioners have several other capabilities compared to vapor-compression technology. TEC modules can be built into a planar structure on walls and false ceiling and are quiet in operation especially suitable for small offices and mini apartments. Cosnier et al. [3] have presented numerical and experimental results of a thermoelectric air-cooling and air-heating system. The maximum cooling power of 50 W per module, with a COP varying between 1.5 and 2 was reached with electrical current of 4 A and maintaining 5°C temperature difference between the hot and cold sides. Cheng et al. [4] have investigated a solar-driven thermoelectric cooling module with a waste heat regeneration unit for green building applications. Their

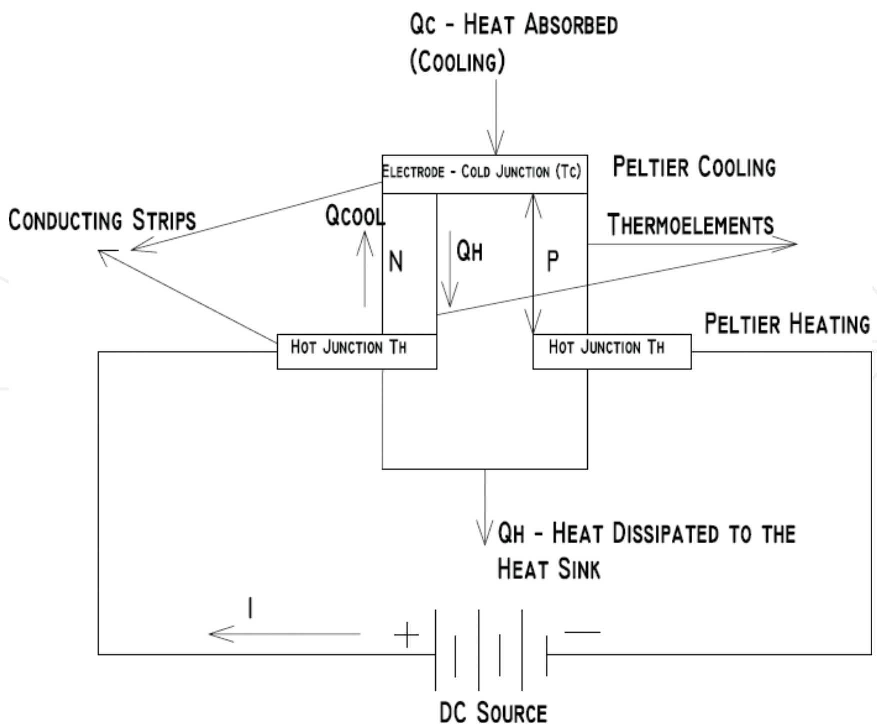

Figure 1. Principle of thermoelectric cooling.

results have shown that TEC system was able to produce 16.2°C temperature difference between the ambient and building zone. However, the TEC COP was relatively low, varying from 0.2 to 1.2 in this study.

Gillott et al. [5] investigated TEC devices for small-scale space's air conditioning building application. A thermoelectric cooling unit was built for 220 W cooling capacity with a maximum COP of 0.46 with input electrical current of 4.8 A for each TEC module. Arenas et al. [6] and Vázquez et al. [7] developed an active thermal window (ATW) and transparent active thermoelectric wall (PTA) for room cooling application for building retrofit applications. In these devices, thermoelements embedded on window glass transfer heat through the glass in order to cool the room. A full-size prototype ATW was installed in a window frame (100 × 100 cm), which was able to generate up to 150 W of cooling power while glass transparency decreased by about 20%. Their work was patented [8]. Most of TEC devices directly cool down the indoor air. Shen et al. [9] investigated a novel thermoelectric radiant air-conditioning system (TE-RAC). The TE-RAC system employs thermoelectric modules as radiant panels for indoor cooling, as well as for space heating by easily reversing the input current. Their analysis of a commercial thermoelectric module, TEC1-12706 with a ZT value of 0.765, have obtained a maximum cooling COP of 1.77 with an electric current of 1.2 A while maintaining cold side temperature at 20°C.

The cooling effect in the TEC module is dependent on parameters such as electric current, the hot and cold side temperatures, the electrical contact resistance between the cold side and the surface of TEC device, thermal and electrical conductivities of thermoelement and thermal resistance of the heat sink on the hot side of TEC module. The required cooling capacity with maximum electric current determines the number of thermoelements in a TEC module. The main disadvantage of thermoelectric cooling module is its poor coefficient of performance (COP), predominantly in large capacity applications [10]. The COP and the cooling capacity of the TEC module can be predicted using the standard module theory based on one dimensional (1-D) heat balance equations, with the assumptions of negligible thermal and electrical contact resistances. The COP estimated from the standard module theory is determined from the hot and cold side temperatures of TEC module and figure of merit, ZT of the thermoelectric material. The design of thermoelectric cooling system is based on temperature difference across the hot and cold sides of the TEC module and the required cooling capacity.

In this chapter, one dimensional (1-D) energy balance model is presented for evaluating system design of a prototype thermoelectric cooling – photovoltaic (TEC-PV) device. The prototype consists of an integrated design with ceiling suspended, wall mounted, rooftop and active façade TEC-PV devices.

2. Energy balance model

The total energy efficiency of photovoltaic driven thermoelectric cooling devices can be increased with enhancement of photovoltaic system efficiency and with the use of thermoelectric materials with better performance. The COP of thermoelectric air conditioning devices powered through photovoltaic modules is typically not higher than 0.6 [10]. With consideration of photovoltaic system efficiency η_{pv}, the total energy efficiency of the system is given by the product of η_{pv} and COP. Mathematically it is written as:

$$E_{TEC-PV} = \eta_{pv} \times COP \tag{1}$$

The values of $E_{TEC\text{-}PV}$ are typically lower than 6%.

Commercial thermoelectric materials are alloys such as Bi_2Te_3, PbTe, SiGe and $CoSb_3$ [11]. Bi_2Te_3 is the most commonly used thermoelectric material. The commercially available thermoelectric materials have highest ZT values around 1.0.

For a particular thermoelectric module with fixed hot/cold side temperatures, the maximum COP at optimum current is given by [11]:

$$COP_{\max, cool} = \frac{T_c}{T_h - T_c} \cdot \frac{\sqrt{1 + ZT_m} - \frac{T_h}{T_c}}{\sqrt{1 + ZT_m} + 1} \tag{2}$$

where ZT_m is the figure-of-merit for thermoelectric material at mean hot and cold side temperature T_m. In calculation of COP, a mean temperature between the hot and cold junction temperatures (with fixed hot side temperature of 300 K with ZT_m = 1) of the thermoelectric module (TEM) is used.

A steady state energy balance model of thermoelectric cooling is used for energy performance assessment. The absorbed (Q_c) heat flux and released (Q_h) heat flux are obtained using Eqs. (3) and (4) respectively. The electric power (P) required to power thermoelectric module (TEM) is obtained from the difference between the absorbed and released heat fluxes (Eq. (5)). In these equations, α, R and K are the Seebeck coefficient, electrical resistance, and thermal conductance of the thermoelectric module. Whereas, I, is the electric current and N is the number of thermocouple legs in the thermoelectric module. The TEM is made up of several thermocouple legs. Thermoelectric leg characteristics are responsible for the resulting TEM performance. R and K are calculated using Eqs. (6) and (7) respectively considering the leg length (L), leg section area (S), thermal conductivity (λ) and electrical resistivity (ρ). The coefficient of performance (COP) of the TEM is the ratio between the absorbed heat and total electric power (including fan power) obtained from Eq. (8). In this chapter, a thermocouple leg made of bismuth telluride (Bi_2Te_3) is considered and its properties are shown in **Table 1** [12]. The thermal resistance between the thermoelectric module and fin plate is assumed to be 0.0161 K/W [12].

Conductivity thermal (W/m-K)	$\lambda(T) = (62605 - 277.7 \cdot T + 0.4131 \cdot T^2)10^{-4}$
Resistivity electrical (Ω·m)	$\rho(T) = (5112 - 163.4 \cdot T + 0.6279 \cdot T^2)10^{-10}$
Seebeck coefficient (Volts/K)	$\alpha(T) = (2224 - 930.6 \cdot T + 0.9905 \cdot T^2)10^{-9}$

Table 1. Bismuth telluride (Bi_2Te_3) properties.

$$Q_c = N \cdot \left(\alpha \cdot I \cdot T_C - 0.5 \cdot R \cdot I^2 - K \cdot \Delta T\right) \quad (3)$$

$$Q_h = N \cdot \left(\alpha \cdot I \cdot T_H + 0.5 \cdot R \cdot I^2 - K \cdot \Delta T\right) \quad (4)$$

$$P = Q_h - Q_c = N \cdot \left(\alpha \cdot I \cdot \Delta T + R \cdot I^2\right) \quad (5)$$

$$R = \frac{L}{S} \cdot \rho \quad (6)$$

$$K = \frac{S}{L} \cdot \lambda \quad (7)$$

$$COP_{cooling} = \frac{Qc}{P} \quad (8)$$

In order to investigate the operating energy consumption in summer, a thermoelectric cooling-photovoltaic (TEC-PV) device is simulated for building data as per **Table 2**, representing sunny, hot and humid outdoor air condition. Properties of TEC-PV device is provided in **Table 3**. **Table 4** provides thermal design properties of TEC-PV device.

2.1. Thermoelectric dehumidification

The room sensible heat factor (RSHF) is defined as the ratio of sensible cooling load to total cooling load (Eq. (9)).

$$RSHF = \frac{Q_{sen}}{Q_{sen} + Q_{lat}} \quad (9)$$

Outdoor air condition	Sunny, hot and humid (DBT: 33–35°C, RH: 75%)			
Floor area	9 m^2			
Room volume	27 m^3			
U-value of exterior wall	0.44 W/m^2 K			
U-value of roof	0.126 W/m^2 K			
Window to wall ratio	0.3			
Lighting power density	0.6 W/ft^2			
Infiltration	0.3 ACH			
Operation schedule	07:00 to 17:00 hours			
Indoor air condition	Dry bulb temperature (DBT): 23°C, RH: 55%			
Room sensible heat factor	0.95	0.9	0.8	0.7
Ventilation rate	20 m^3/h	40 m^3/h	90 m^3/h	120 m^3/h
Peak sensible cooling load	1 kW			
Peak latent cooling load	0.05 kW	0.12 kW	0.28 kW	0.48 kW

Table 2. Building data.

TEC module	**TEC1-12710**		**Photovoltaic module**	
Operational voltage	12 V DC		Total power required	1.8 kW
Current max	10.5 Amp		Area required	18 m^2
Voltage max	15.2 V		Roof area	9 m^2
Power max	85 W		South façade area	9 m^2
Nominal power	60 W		Nominal power	300 W
Thermocouples	127		Number of PV modules	8
Dimensions	40 × 40 × 3.5 mm		On roof	4
Total number of TEC modules	30		On façade	4
Placement position	Inside ceiling duct	Wall mounted	Battery backup	10.8 kWh
TEC modules	10	20	Battery @ 12 V DC	900 AH

Table 3. Thermoelectric cooling (TEC)-photovoltaic (TEC-PV) device properties.

Relative humidity is a key control parameter for thermal comfort inside a room. The performance of a thermoelectric cooling device depends mainly on optimal positioning and layout of heat exchange & transfer surfaces.

The total heat transfer rate (Q_c) of the fin heat exchanger on the cold side of the thermoelectric module (TEM) is given by [13]:

$$Q_c = h_c \cdot A_c \cdot (t_r - t_c) + m_w \cdot H_c \quad (10)$$

where h_c is the coefficient of convective heat transfer (W/m^2K), A_c is the heat transfer area (m^2), t_r is the room temperature (°C), t_c is average temperature of cold fins (°C) and H_c is the latent heat of condensation (J/kg-K).

The dehumidifying rate (m_w, kg/s) is calculated as [13]:

$$m_w = \frac{m_a \cdot (\phi_1 - \phi_2)}{T_{\text{sec}}} \quad (11)$$

where m_a is the mass of the wet air inside the room (kg), T_{sec} is the dehumidifying period (sec), Φ_1 and Φ_2 are the relative humidity before and after dehumidification (%).

The convective heat transfer coefficient between adjacent fins and room air is given by [14]:

$$h_c = 0.517 \cdot \frac{k_{air}}{H} \cdot Ra^{0.25} \quad (12)$$

where k_{air} is the thermal conductivity of air (W/m-K), H is the height of fin (m) and Ra is the dimensionless Rayleigh number.

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Parameter	Values
Thermal resistance of cold side	0.1 K/W
Thermal resistance of hot side	0.7 K/W
TEM thermal conductivity	0.51 W/K
TEM electrical resistance	2.236 Ω
Aluminum thermal conductivity	230 W/m-K
Thickness of aluminum sheet	1.6 mm
Insulation thickness	40 mm
Insulation thermal conductivity	0.05 W/m-K
Insulation specific heat capacity	500 J/kg-K
Thermal contact resistance	0.1 m^2K/W
Fin thickness	1 mm
Fin profile length	20 mm
Fin spacing	3 mm
Number of fins (cold side) per TEC module	10
Number of fins (hot side) per TEC module	10
Thermal resistance (cold side fins)	1.2 K/W
Thermal resistance (hot side fins)	0.76 K/W
Thermal resistance between TEM and fin plate	0.0161 K/W
Height of solar PV wall mounted exhaust duct	3000 mm
Width of solar PV wall mounted exhaust duct	2 Nos.@ 1500 mm
Absorption coefficient of PV panel	0.9
Thickness of PV ventilated exhaust duct	150 mm
Density of PV panel	2300 kg/m^3
Specific heat capacity of PV panel	750 J/kg-K
Thickness of PV panel	5 mm
Number of TEC modules with ceiling suspension duct (position 1)	10 covering 1.60 m^2
Number of TEC modules on wall (position 2)	20 covering 3.60 m^2
Heat transfer fluid	Air
DC power for each fan	1.5 W
Number of DC fans on supply side	2
Number of DC fans on exhaust side	2
Maximum ventilation rate per fan	60 m^3 h^{-1}

Table 4. Thermal design properties of TEC-PV device.

2.2. Exergy expressions

The specific exergy of fresh moist air into the duct is expressed as [15]:

$$
\begin{aligned}
ex_{f,in} = \left(c_{pa} + w_{f,in} \cdot c_{pv}\right)\left[T_{f,in} - T_o - T_o \cdot \ln\frac{T_{f,in}}{T_o}\right] \\
+ R_a \cdot T_o \left[\left(1 + 1.608w_{f,in}\right) \cdot \ln\frac{\left(1 + 1.608w_{f,in}\right)}{\left(1 + 1.608w_o\right)}\right. \\
\left. + 1.608 \cdot R_a \cdot T_o \cdot w \cdot \ln\frac{w_{f,in}}{w_o}\right]
\end{aligned}
\tag{13}
$$

The reference temperature (T_o) and the humidity ratio (w_o) is defined as the indoor air temperature and humidity ratio during hot and humid season. R_a is the thermal resistance of air. c_{pa} is specific heat of moist air and c_{pv} is specific heat inside the duct.

Thus from Eq. (13), total exergy of the fresh air flow into the duct is expressed as:

$$
Ex_{f,in} = \rho \cdot M_a \cdot ex_{f,in} \tag{14}
$$

where ρ is density of air and M_a is airflow rate m^3/h.

The exergy of the heat transferred between the fresh air and TEM is expressed as:

$$
Ex_{Qf} = \left[1 - \frac{T_o}{T_c}\right] \cdot Q_f \tag{15}
$$

where Q_f is heat transfer rate (W).

The system exergy efficiency is expressed as:

$$
\eta_{Ex} = \frac{Ex_{eff}}{Ex_{\sup}} \times 100\% = \frac{\left[Ex_{f,out} - Ex_{f,in}\right]}{Ex_{elec}} \times 100\% \tag{16}
$$

where Ex_{eff} is effective Exergy, Ex_{sup} is electrical exergy supplied.

3. Design considerations for thermoelectric cooling photovoltaic (TEC-PV) devices

a. **Building integration parameters:** Thermoelectric cooling (TEC) devices can be fixed in a building on wall and ceiling as radiant cooling panels. Due consideration should be given for placing thermoelectric modules with or without heat sinks. Heat sinks can be placed towards building interior zone and towards exterior zone. The thermoelectric modules can be placed on a cut section of a wall, with provision of cooling the hot side heat sink. The thermoelectric cooling devices can also be fixed on a window or a skylight. Proper protection has to be ensured from air infiltration and direct solar radiation for TEC devices fixed on windows and skylights. The mode of operation for winter can be reversed by changing the direction of current of thermoelectric modules. TEC devices can also be fixed inside air supply ventilation ducts. Buildings requiring cooling and heating with dual duct ventilation system are good choice for using thermoelectric devices inside ducts.

b. **Thermoelectric module (TEM) system design:** It depends on thermoelement length, number of thermocouple legs, cross sectional area, slenderness ratio. Both COP and cooling capacity of TEC devices are dependent on thermoelement length. Keeping cross sectional area constant, larger length of thermoelectric element achieves greater COP, while shorter length thermoelectric element achieves larger cooling capacity. Commercially available thermoelectric modules have thermoelement length in the range from 1 to 2.5 mm [11]. Cooling power capacity increases with decreasing the ratio of thermoelement length to cross sectional area.

c. **Thermoelectric cooling (TEC) system design:** It depends on cooling system thermal design, heat sinks' geometry, heat transfer area, heat transfer coefficients of hot and cold side heat sinks, thermal and electrical contact resistances, fins placement and design, heat sinks integrated with thermosyphon, heat transfer fluids, phase change materials [16]. Thermal contact resistance at the interface layer of thermocouple legs is critical for its cooling capacity and COP. Because of this reason, it is not essential that increase in ZT of thermoelectric material will increase ZT of a thermocouple leg because of the presence of interface layer. The performance and efficiency of heat sinks at hot and cold side effects the cooling COP. Air cooled heat sink (forced convection with fan, example thermal resistances of 0.54–0.66 K/W [11], water cooled heat sink (thermal resistance of 0.108 K/W [11], and heat sink integrated with heat pipe (thermal resistance 0.11 W/K are most commonly used techniques. It has been found that heat pipes are not preferred as they eventually have to release heat to either air or water eventually. Heat sinks with nanofluid have potential to achieve lower thermal resistance. Hot side heat sink performance is of greater importance due to higher heat flux density in comparison to heat flux at cold side heat sink. Allocation ratios of heat transfer area with heat transfer coefficients between hot and cold sides are important for achieving maximum COP. Typical allocation ratio is around 0.36–0.47 [11]. Maximum COP with optimum cooling capacity can be achieved at given hot and cold sides fluid temperatures.

d. **Photovoltaic (PV) power system design:** The most conventional way is to install PV panels on rooftop and façade of a building with thermoelectric cooling (TEC) devices. In this way, excess power can also be stored in a battery system. In case of non-availability of solar PV power, power can be fed directly from the battery backup. Active façade ventilation can be integrated with TEM and PV devices [17–19]. For heating requirements during winter season, these active façade elements can supplement with heating from TEM and façade integrated PV ventilated devices [20–22].

e. **Performance & operational parameters optimization:** It depends on electric current input, coolants, cooling methods of hot side heat sink, mass flow rate, ventilation requirements. Performance indicators are COP and energy efficiency of devices and systems.

4. System design of thermoelectric cooling-photovoltaic (TEC-PV) device

4.1. Importance of outdoor air ventilation

Indoor air quality improvement is achieved by bringing in outdoor air into the building environment. Introduction of outdoor air increases energy consumption of the conventional air conditioning system. In the conventional air conditioning system, limited energy conservation is achieved through heat recovery ventilators, such as fixed-plate, run-round coil and rotary wheel. In these heat recovery ventilators, passive means are employed through temperature and humidity difference between fresh outdoor air and return air, which are dependent on outdoor weather conditions. However in a thermoelectric cooling-photovoltaic (TEC-PV) device, dedicated outdoor air is cooled and dehumidified by active means through input of solar power. The design is assessed by estimating the cooling capacity for selection of a TEC module according to the temperature difference between the hot and cold side. The current required to operate the TEC module can be obtained from trials and also checked from manufacturer data curve to meet the actual cooling capacity. Energy efficiency of a thermoelectric cooling (TEC) device is defined as the ratio of the cooling capacity to the electrical energy consumed. Exergy analysis is based on quality of energy, used for evaluating energy process with respect to ideal thermodynamic equality. Exergy analysis is used for identifying exergy losses, which is used for understanding of irreversible losses of energy conversion in its system design.

The system design consists of: (i) outdoor fresh air ventilation; (ii) thermoelectric cooling (TEC); (iii) building integration; (iv) photovoltaic power generation; and (v) exhaust air ventilation.

4.2. Operation

The outdoor fresh air is cooled down and dehumidified as it flows over a heat sink/exchanger attached to thermoelectric cooling (TEC) module. The cool air enters the indoor environment which is to be maintained at 23°C and 55% RH. The stale air is taken out through ducted exhaust air ventilation system. The exhaust air also cools down the heat sink/exchanger attached to hot side of thermoelectric module (TEM). The outdoor fresh air is introduced into the single zone building air volume at varying rates as mentioned in **Table 2**. Four DC fans are used to provide power for forced airflow. Two of them are installed on supply fresh air side and other two are installed on exhaust air side. The input power for each fan is 1.5 W with airflow rate at 60 $m^3\ h^{-1}$. The maximum fresh air supply in the room is 120 $m^3\ h^{-1}$ at full capacity. The outside fresh air is at 33°C and 75% RH. Eight solar PV modules of 300 W each are used to power thirty TEC modules of 60 W each and four DC fans of 1.5 W each. Four solar PV modules are placed on south façade while other four are fixed on roof top. The maximum sensible cooling load in the building zone is 1 kW while maximum latent load varies up to 0.48 kW.

Principle:

Two-stage Dehumidification (Condensation): Depending on dew point of the air, cooling dehumidification and iso-thermal dehumidification can take place on fins inside cooling duct and on wall with TEC modules.

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Heat transfer process: A steady state is reached when temperature of air remains constant with heat transfer from the cold side fins. Cold side fins are placed both on supply duct and inside room. Hot side fins are placed on exhaust duct and exterior of room wall surface. The height of heat transfer surface inside the duct is 0.5 m and height of heat transfer surface inside the room is 2.5 m. The condensation phenomenon at initial dehumidification will result in rapid temperature drop of cold side fins. The dehumidification will continue further at steady temperature of cold side fins. In order to improve the performance of fins for dehumidification, rapid elimination of condensed water is necessary. This is achieved by specially treated heat transfer surfaces (fins) with superhydrophilic or super water repellant surfaces [13].

The schematic of a building zone with two stage cooling through TEC modules by means of supply duct and wall mounted TEC modules with solar PV façade exhaust duct is illustrated in **Figure 2**. The performance characteristics with voltage variation of analyzed TEC1-12710 modules in TEC calculator is provided in **Figure 3**. The variation in theoretical values of COP (cooling) and temperature (cold) for $ZT_m = 1$ is provided in **Figure 4**. The variation in theoretical values of cooling capacity with temperature difference is provided in **Figure 5**. The variation of theoretical heat transfer coefficient with height of heat transfer surface (fins) is provided in **Figure 6**. The theoretical variation of cooling capacity load served inside room with height of heat transfer surface (fins) is provided in **Figure 7**. The variation of theoretical exergy of air cooled inside the room with cold side temperature and Tout at 306 K is illustrated in **Figure 8**. All the results are based on theoretical values irrespective of actual performance values of the prototype TEC-PV device.

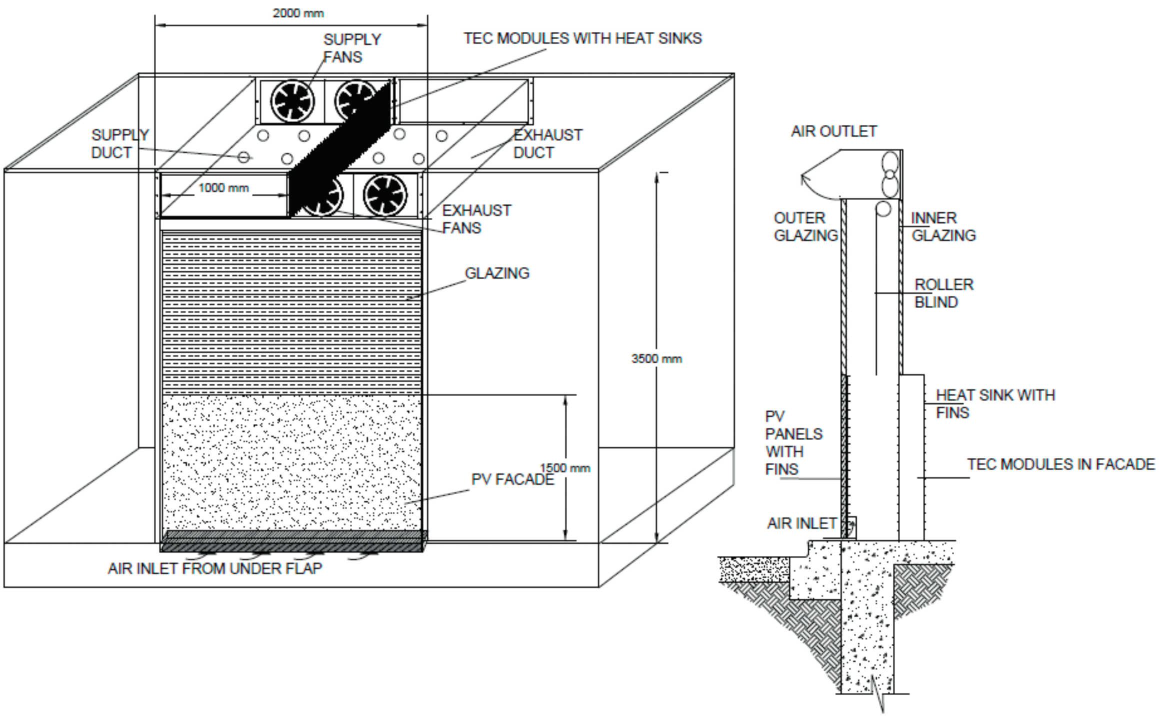

Figure 2. Schematic of a building room zone with TEC modules and PV ventilated façade.

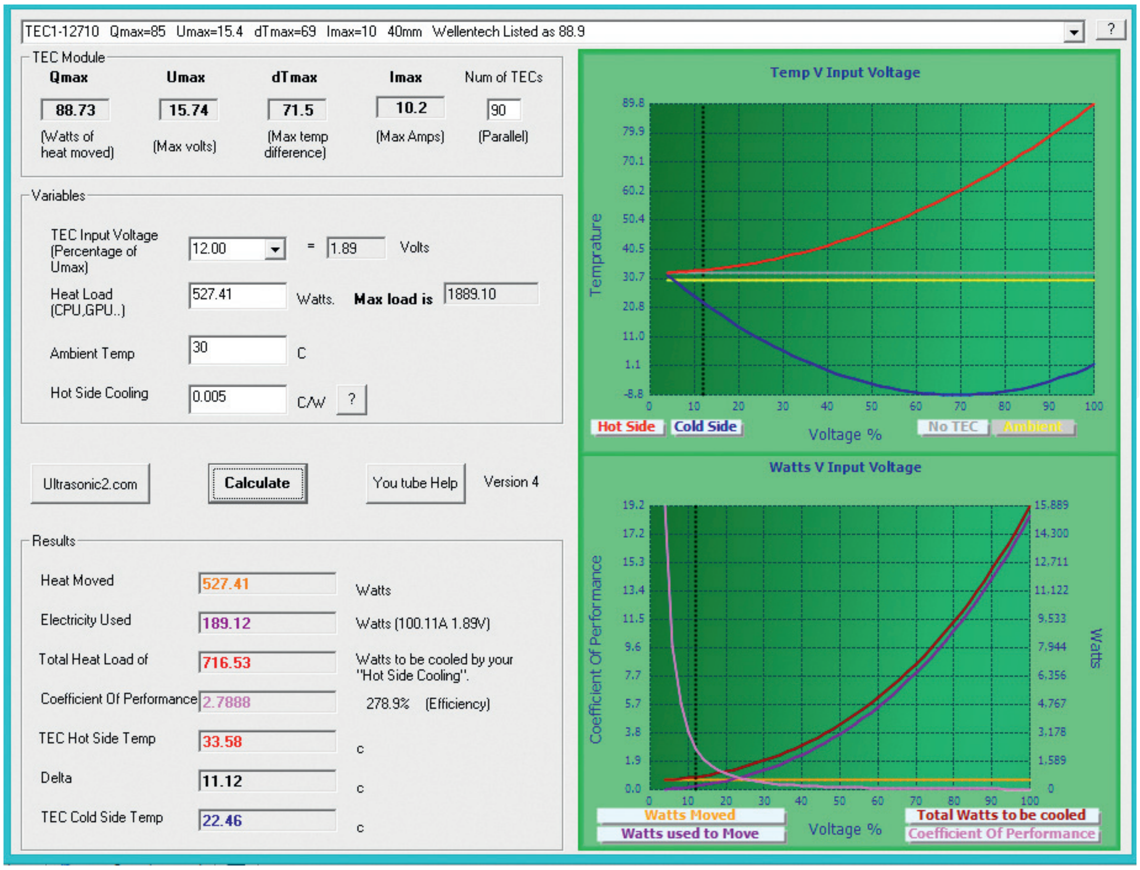

Figure 3. Performance characteristics of TEC1-12710 module with voltage variation analyzed in TEC calculator.

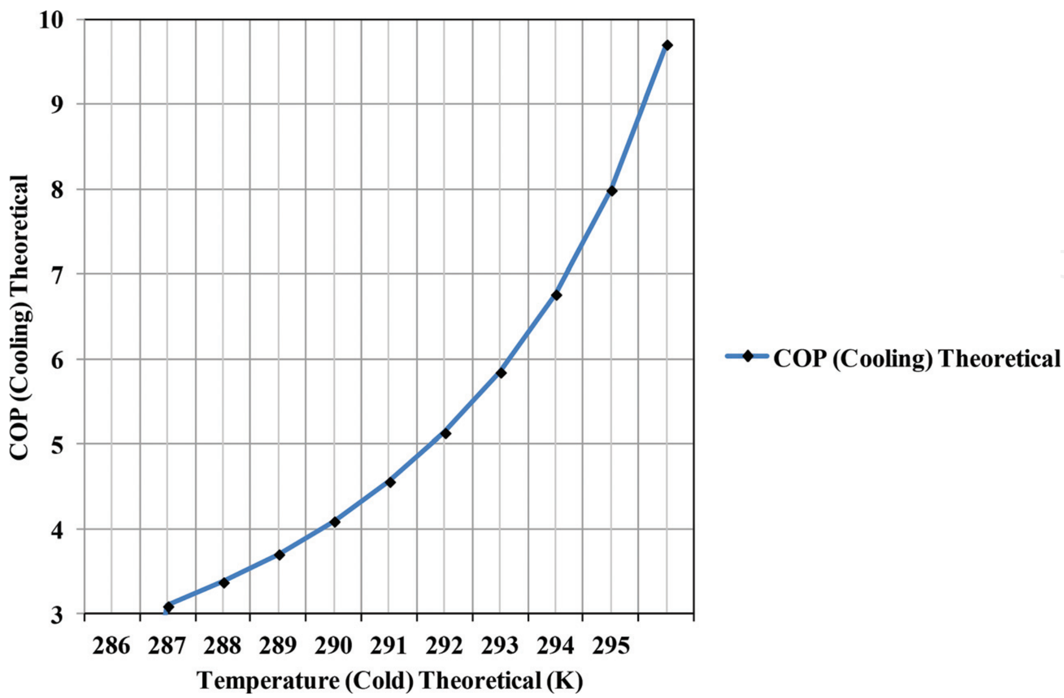

Figure 4. Variation in theoretical values of COP (cooling) and temperature (cold) for $ZT_m = 1$.

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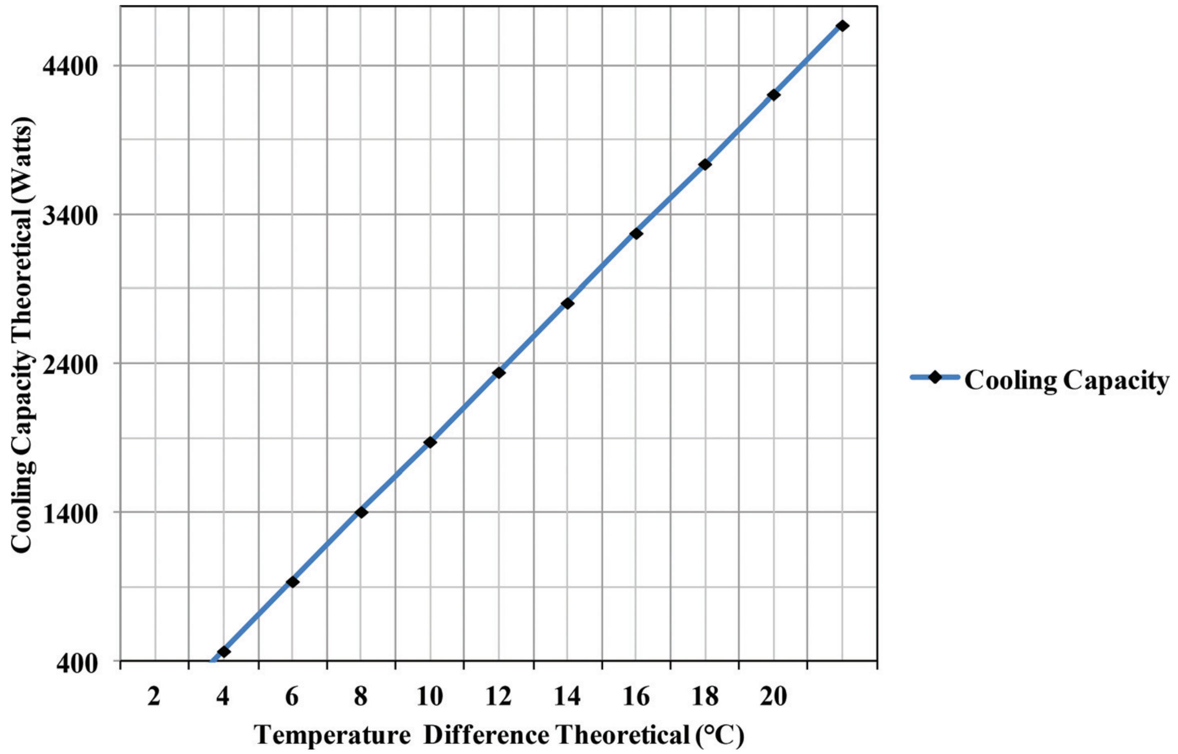

Figure 5. Variation in theoretical values of cooling capacity with temperature difference.

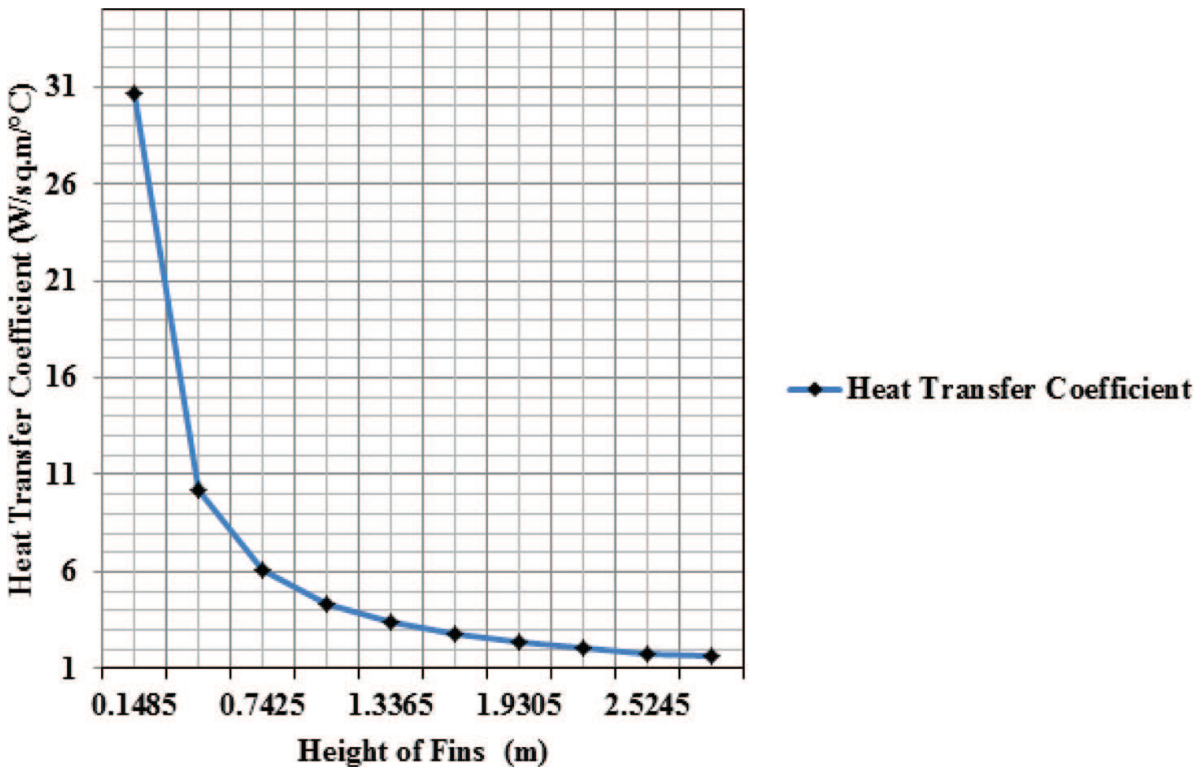

Figure 6. Variation of heat transfer coefficient with height of heat transfer surface (fins).

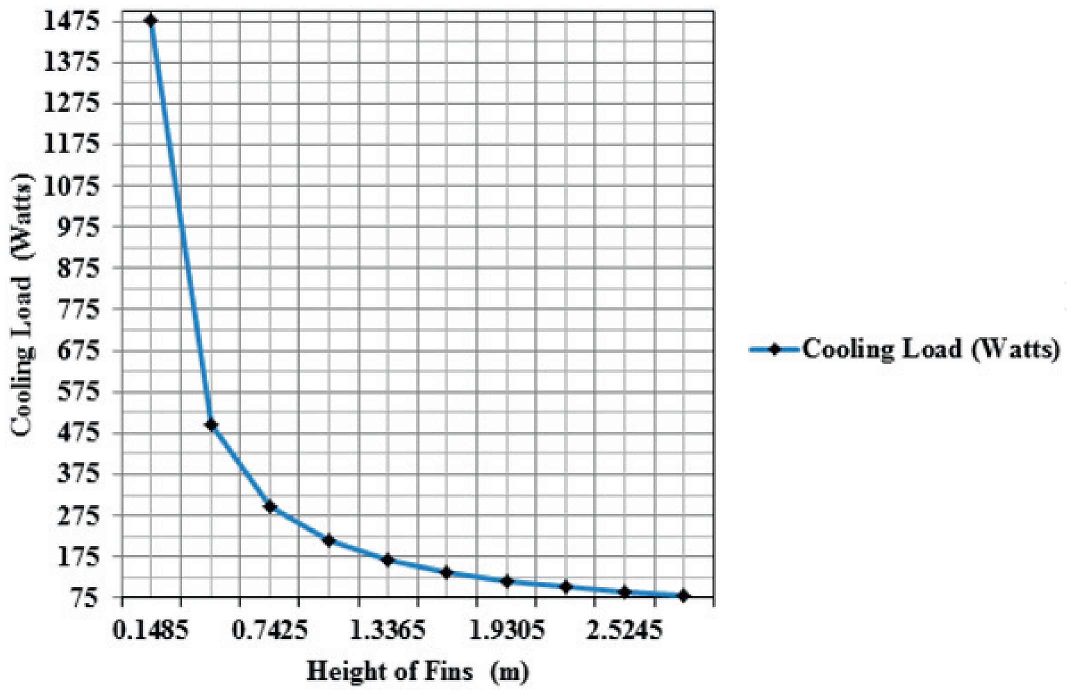

Figure 7. Variation of cooling capacity load served inside room with height of heat transfer surface (fins).

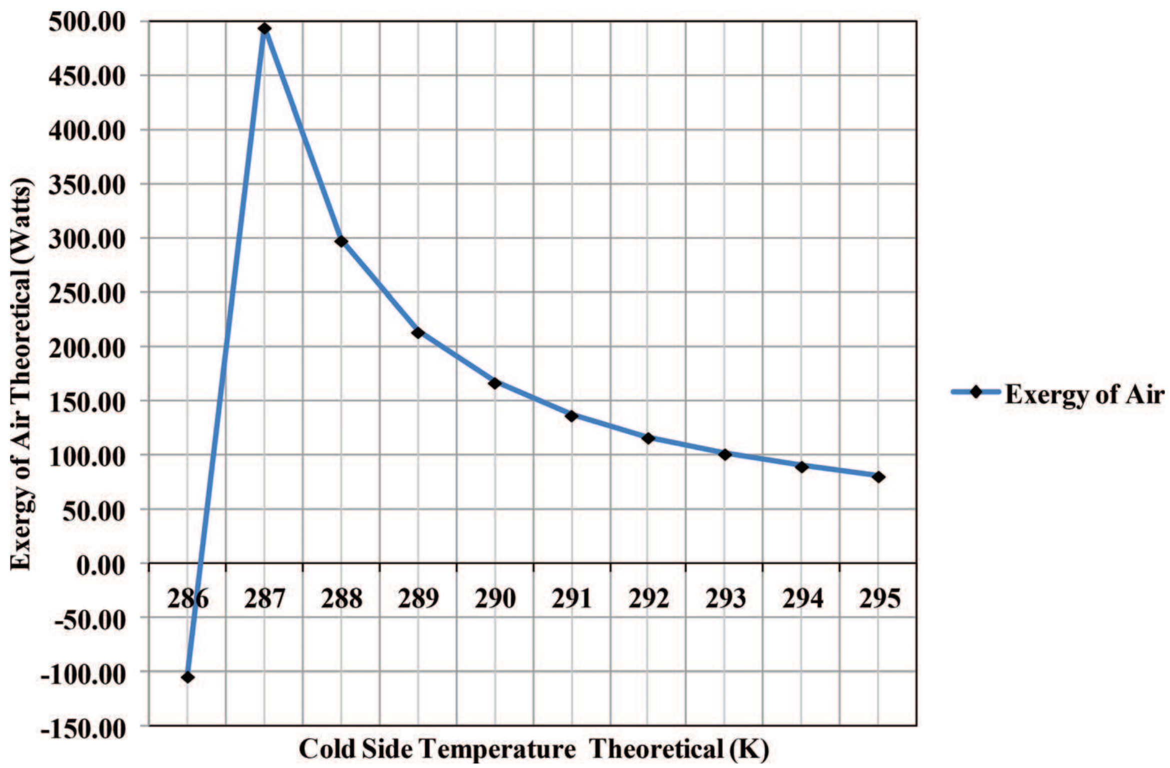

Figure 8. Variation of theoretical exergy of air inside room with cold side temperature and Tout = 306 K.

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5. Conclusion

Thermoelectric cooling (TEC) is one of the specialized areas in "Thermoelectrics." This chapter has presented the summary of energy balance model parameters representing various performance characteristics of building-integrated thermoelectric cooling-photovoltaic (TEC-PV) devices. The cooling performance of thermoelectric modules for air-conditioning applications is a sustainable technology though not competitive with conventional vapor compression technology. There is significant growing interest level in thermoelectric cooling (TEC) because of their useful control aspects. This is because TEC modules are readily operated at partial load by changing the electric current. Moreover, there is increase in cooling COP with reduction of cooling power. Modular capability is the key merit of thermoelectric cooling (TEC) devices. These devices do not generate noise, thus are of considerable interest in many building applications in which noise is a significant factor. Furthermore, key advantage is the operation of thermoelectric cooling (TEC) devices without requirement of polluting refrigerants.

Air-conditioning of fresh outdoor air for direct indoor use through proper system design of supply air ventilation system and exhaust air ventilation system is another key benefit of thermoelectric cooling (TEC). In addition, photovoltaic (PV) roof-top power generation and photovoltaic (PV) ventilated façade are integrated into the system design, thus making it further sustainably sound in terms of input electricity requirements through green power and active ventilation system for supply and exhaust air. Finally, thermoelectric modules (TEM) offer air-conditioning solutions with flexible electrical loads in contemporary context of smart energy systems for buildings. Thermoelectric modules (TEM) have best advantage of their reversible operation as heating and cooling devices obtained by changing the direction of electric current. The future work comprises of advanced modeling and simulation of the presented prototype through thermoelectric modules (TEMs) operation as heating and cooling devices powered by photovoltaic modules.

Nomenclature

η_{pv} photovoltaic system efficiency

COP coefficient of performance

ZT_m figure-of-merit for thermoelectric material

Q_c absorbed heat flux, W

Q_h released heat flux, W

P electric power, W

α Seebeck coefficient, Volts/K

R electric resistance, Ohms

h_c coefficient of convective heat transfer (W/m^2K),

A_c heat transfer area (m^2)

t_r room temperature (°C)

t_c temperature of cold fins (°C)

Φ_1 relative humidity before dehumidification (%)

Φ_2 relative humidity after dehumidification (%)

Ra Rayleigh number

T_o outside temperature (°C)

K thermal conductance, W/m^2K

I electric current, amperes

N number of thermocouple legs

L thermoelectric leg length, m

S leg section area, m^2

λ thermal conductivity, W/m-K

ρ electrical resistivity, Ω·m

Q_{sen} sensible cooling load, W

Q_{lat} latent load, W

H_c latent heat of condensation (J/kg-K)

m_a mass of the wet air inside the room (kg)

T_{sec} dehumidifying period (sec)

k_{air} thermal conductivity of air (W/m-K)

H height of fin (m)

T_c cold side fin temperature (°C)

Ex_{Qf} exergy of fresh air, W

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