Cooling load and noise characterization modeling for photovoltaic driven building integrated thermoelectric cooling devices

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Abstract. Photovoltaic driven thermoelectric cooling devices are investigated for installation in a modular outdoor test-room. Because of Peltier effect in a thermoelectric cooling (TEC), heating and cooling is achieved by applying a voltage difference across the thermoelectric module. Theoretical design modeling of cooling load and noise characterization of building integrated Thermoelectric (TEC) Devices is analyzed. System design of photovoltaic driven TEC devices is investigated with varying fresh outdoor ventilation rates. Building integrated design of TEC devices inside ceiling suspended duct along with TEC devices mounted on wall driven by rooftop and active façade photovoltaic devices is considered in the analysis. In this way, two-stage dehumidification is achieved by two different sets of TEC devices. The investigation is conducted for effect of voltage, air flow rate and height of fin heat transfer surface. Expressions along with results for noise characterization in photovoltaic driven building integrated TEC devices are also provided.

1 Introduction

Thermoelectric module is a solid-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 semiconductor elements, to generate thermoelectric cooling (viz., Peltier – Seebeck effect) when a voltage difference in appropriate direction is applied through the connected circuit. 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).

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 paper energy balance model and noise characterization 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 [1].

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 [2]. 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:

\[ E_{TEC-PV} = \eta_{pv} \times COP \]  

The values of \( E_{TEC-PV} \) are typically lower than 6%.
Commercial thermoelectric materials are alloys such as Bi$_2$Te$_3$, PbTe, SiGe and CoSb$_3$. Bi$_2$Te$_3$ 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 [3]:

$$COP_{\text{max, cool}} = \frac{T_c}{T_h - T_c} \cdot \frac{\sqrt{1 + ZT_m} - \frac{T_h}{T_c}}{\sqrt{1 + ZT_m} + 1}$$ (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.

$$COP_{\text{cooling}} = \frac{Q_c}{P}$$ (3)

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 1, representing sunny, hot and humid outdoor air condition. Properties of TEC-PV device is provided in Table 2.

### Table 1: Building Data

| Outdoor Condition       | Air          | 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 Condition        | Air          | Dry Bulb Temperature (DBT): 23 °C, RH: 55%  |
| Room Sensible Heat Factor| 0.95        |
| Ventilation Rate        | 20 m$^3$/h   |
| Peak sensible cooling load | 1 kW         |
| Peak latent cooling load | 0.05 kW      |

### Table 2: Thermoelectric Cooling (TEC)-Photovoltaic (TEC-PV) Device Properties

| TEC Module | Module | Photovoltaic Module | Operational Voltage | Total Power | Required kW |
|------------|--------|---------------------|---------------------|-------------|-------------|
| TEC1-12710 |        |                     | 12 V DC             | 1.8         |             |
| 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$^2$             |             |             |

### 2.1. Thermoelectric Dehumidification

The room sensible heat factor (RSHF) is defined as the ratio of sensible cooling load to total cooling load (Equation 4).

$$RSHF = \frac{Q_{\text{sen}}}{Q_{\text{tot}}}$$ (4)

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 & 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

$$Q_c = h_c \cdot A_c \cdot (t_i - t_r) + m_w \cdot H_e$$ (5)

Where, $h_c$ is the coefficient of convective heat transfer (W/m$^2$K), $A_c$ is the heat transfer area (m$^2$), $t_i$ is the room temperature (°C), $t_r$ is average temperature of cold fins (°C) and $H_e$ is the latent heat of condensation (J/kg-K). The dehumidifying rate ($m_w$, kg/s) is calculated as [5]:

$$m_w = \frac{m_a \cdot (\Phi_1 - \Phi_2)}{T_{sec}}$$ (6)

Where, $m_a$ is the mass of the wet air inside the room (kg), $T_{sec}$ is the dehumidifying period (sec), $\Phi_1$ and $\Phi_2$ are the relative humidity before and after dehumidification (%). The convective heat transfer coefficient between adjacent fins and room air is [6]:

$$h_c = 0.517 \cdot \frac{k_{air}}{H} \cdot \frac{T_{sec}}{0.25}$$ (7)
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. **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 m³ h⁻¹. The maximum fresh air supply in the room is 120 m³ 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:** There is two-stage cooling. 1st stage inside fresh air supply duct through TEC modules fixed inside air supply duct; 2nd stage-Inside the room through TEC modules fixed on inner wall. Extra cooling is achieved inside the room through TEC modules on façade. **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. 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 a. The performance characteristics with voltage variation of analysed TEC1-12710 modules in TEC calculator is provided in Figure 2 b. The variation in theoretical values of COP (cooling) and temperature (cold) for $Z_{m}=1$ is provided in Figure 3 a. The variation in theoretical values of cooling capacity with temperature difference is provided in Figure 3 b. The variation of theoretical heat transfer coefficient with height of heat transfer surface (fins) is provided in Figure 4 a. The theoretical variation of cooling capacity loaded inside room with height of heat transfer surface (fins) is provided in Figure 4 b. All the results are based on theoretical values irrespective of actual performance values of the prototype TEC-PV device.
4 Noise Characterization

A unified theory for stresses and oscillations is proposed by the author [9]. The following standard measurement equations are derived and adopted from the standard definitions for sources of noise interference [10, 11, 12, 13, 14, 15].

Noise of Sol: For a pack of solar energy wave, the multiplication of solar power storage and the velocity of light gives solar power intensity I. On taking logarithm of two intensities of solar power, I_1 and I_2, provides intensity difference. It is mathematically expressed as:

$$\text{Sol} = \log(I_1/I_2)^{-1}$$  \hspace{1cm} (8)$$

Whereas logarithmic unit ratio for noise of sol is expressed as Sol. The oncisol (oS) is more convenient for solar power systems. The mathematical expression by the following equality gives an oncisol (oS), which is 1/11 th unit of a Sol:

$$oS = \pm 11 \log(I_1/I_2)^{-1}$$  \hspace{1cm} (9)$$

Noise of Them: For a pack of heat energy wave, the multiplication of total power storage and the velocity of light gives heat power intensity I. The pack of solar energy wave and heat energy wave (for same intensity I), have same energy areas, therefore their units of noise are same as Sol.

Noise of Scattering: For a pack of fluid energy wave, the multiplication of total power storage and the velocity of fluid gives fluid power intensity I. On taking logarithm of two intensities of fluid power, I_1 and I_2, provides intensity difference. It is mathematically expressed as:

$$S_{ip} = \log(I_1/I_2)^{-1}$$  \hspace{1cm} (10)$$
Whereas, logarithmic unit ratio for noise of scattering is Sip. The oncisel (oS) is more convenient for fluid power systems. The mathematical expression by the following equality gives an oncisel (oS), which is 1/11th unit of a Sip:

\[ \text{oS} = \pm 11 \log(I_1/I_2) \]  

(11)

For energy area determination for a fluid wave, the water with a specific gravity of 1.0, is the standard fluid considered with power of \( \pm 1 \text{ Wm}^{-2} \) for a reference intensity \( I_2 \).

Noise of Elasticity: For a pack of sound energy wave, the product of total power storage and the velocity of sound gives sound power density \( I \). On taking logarithm of two intensities of sound power, \( I_1 \) and \( I_2 \), provides intensity difference. It is mathematically expressed as:

\[ \text{Bel} = \log(I_1/I_2) \]  

(12)

Whereas, logarithmic unit ratio for noise of elasticity is Bel. The oncisel (oS) is more convenient for sound power systems. The mathematical expression by the following equality gives an oncisel (oS), which is 1/11th unit of a Bel:

\[ \text{oB} = \pm 11 \log(I_1/I_2) \]  

(13)

There are following elaborative points on choosing an oncisel as 1/11th unit of noise [15, 16]:

i) Reference value used for \( I_2 \) is -1 W m\(^{-2} \) on positive scale of noise and 1 W m\(^{-2} \) on negative scale of noise. In a power cycle, all types of wave form one positive power cycle and one negative power cycle [9]. Positive scale of noise has 10 positive units and one negative unit. Whereas, negative scale of noise has 1 positive unit and 10 negative units;

ii) Each unit of sol, sip and bel is divided into 11 parts, 1 part is 1/11th unit of noise;

iii) The base of logarithm used in noise measurement equations is 11;

iv) Reference value of \( I_2 \) is -1 W m\(^{-2} \) with \( I_1 \) on positive scale of noise, should be taken with negative noise measurement expression (see Eqs 9, 11 and 13), therefore it gives positive values of noise;

v) Reference value of \( I_2 \) is 1 W m\(^{-2} \) with \( I_1 \) on negative scale of noise, should be taken with positive noise measurement expression (see Eqs 9, 11 and 13), therefore it gives negative values of noise.

The choosing of oncisel in noise units is done so as to have separate market product & system of noise scales and their units distinguished from prevailing decibel units (which has its limitations) in the International System of Units. More discussions on energy conversion, noise characterization theory and choice of noise scales and its units are presented in many papers by the author [15, 16]. Tables 3, 4, 5 and 6 have presented sensitivity analysis and noise characterization values for the exterior duct based on mass flow rate, solar irradiation and size of duct. Appendix has provided noise calculation charts.

### Table 3. Temperature difference and noise of sol with solar irradiation (air velocity: 0.75 ms\(^{-1} \))

| Solar irradiation (Wm\(^{-2} \)) | Air Temperature Difference (°C) | Noise of Sol (oC) |
|---------------------------------|--------------------------------|------------------|
| 450                             | 15.50                          | 28               |
| 550                             | 18.90                          | 28.93            |
| 650                             | 22.40                          | 29.7             |
| 750                             | 25.90                          | 30.36            |
| 850                             | 29.40                          | 30.91            |

### Table 4. Temperature difference and noise of scattering with air velocity (\( S = 650 \text{ Wm}^{-2} \))

| Air velocity (ms\(^{-1} \)) | Fluid Power (Wm\(^{-2} \)) | Air Temperature Difference (°C) | Noise of Scattering (oS) |
|-----------------------------|-----------------------------|--------------------------------|--------------------------|
| 1.35                        | 47.62                       | 15.28                          | 17.72                    |
| 1.05                        | 37.0                        | 18.22                          | 16.50                    |
| 0.75                        | 26.45                       | 22.40                          | 15.02                    |
| 0.45                        | 15.87                       | 28.15                          | 12.65                    |
| 0.15                        | 05.29                       | 29.80                          | 07.64                    |

### Table 5. Mass flow rate and noise of therm with (ΔT)

| Mass flow rate (Kg s\(^{-1} \)) | Thermal Power (Wm\(^{-2} \)) | Noise of Therm (oS) (oncisel) | Sound Pressure (N m\(^{-2} \)) |
|---------------------------------|-----------------------------|------------------------------|-------------------------------|
| 15.50                           | 71.09                       | 0.00136                      | 117.65                        |
| 18.90                           | 80.32                       | 0.001275                     | 103.85                        |
| 22.40                           | 89.6                        | 0.00120                      | 89.6                          |
| 25.90                           | 99.28                       | 0.00115                      | 76.0                          |
| 29.40                           | 108.8                       | 0.00111                      | 61.59                         |
| 30.91                           | 117.65                      | 0.00108                      | 18.8980                      |

### Table 6. Noise of elasticity with air particle velocity (Impedance \( Z_0 = 413 \text{ Ns} \cdot \text{m}^{-3} \) at 20°C)

| Air velocity (m\(^{-1} \)) | Fluid Power (Wm\(^{-2} \)) | Noise of Scattering (oS) (oncisel) | Sound Power Intensity (Wm\(^{-2} \)) |
|-----------------------------|-----------------------------|-----------------------------------|-----------------------------------|
| 1.35                        | 47.62                       | 17.72                             | 577.5                             |
| 1.05                        | 37.0                        | 16.50                             | 433.65                           |
| 0.75                        | 26.45                       | 15.02                             | 309.75                           |
| 0.45                        | 15.87                       | 12.65                             | 232.31                           |
| 0.15                        | 05.29                       | 9.29                              | 0.0171                           |

### Table 7. Mass flow rate and noise of therm with (ΔT)

| Mass flow rate (Kg s\(^{-1} \)) | Thermal Power (Wm\(^{-2} \)) | Noise of Therm (oS) (oncisel) | Sound Pressure (N m\(^{-2} \)) |
|---------------------------------|-----------------------------|------------------------------|-------------------------------|
| 15.50                           | 71.09                       | 0.00136                      | 117.65                        |
| 18.90                           | 80.32                       | 0.001275                     | 103.85                        |
| 22.40                           | 89.6                        | 0.00120                      | 89.6                          |
| 25.90                           | 99.28                       | 0.00115                      | 76.0                          |
| 29.40                           | 108.8                       | 0.00111                      | 61.59                         |
| 30.91                           | 117.65                      | 0.00108                      | 18.8980                      |

### CONCLUSIONS

Thermoelectric cooling (TEC) is one of the specialized areas in “Thermoelectrics”. This paper has presented the summary of energy modeling parameters representing various cooling load performance and noise characteristics of building integrated thermoelectric cooling-photovoltaic (TEC-PV) devices. 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 cooling (TEC) because of their useful control aspects. 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. Thermoelectric modules (TEM) offer air-conditioning solutions with flexible electrical loads in contemporary context of smart energy systems for buildings. Finally, the noise interference and characterization equations as per speed of a composite
wave are presented. The noise measurement equations and their units are described depending on their speed of noise interference. Some examples of noise characterization are also presented.

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Nomenclature

| Symbol | Description |
|--------|-------------|
| ηpv | Photovoltaic system efficiency |
| K | Thermal Conductance, W/m²K |
| COP | Coefficient of performance |
| I | Electric Current, Amperes |
| ZTm | Figure-of-merit for thermoelectric material |
| N | Number of thermocouple legs |
| Qc | Absorbed heat flux, W |
| L | Thermolectric leg length, m |
| Qt | Released heat flux, W |
| S | Leg section area, m² |
| P | Electric power, W |
| λ | Thermal conductivity, W/m-K |
| hc | Coefficient of convective heat transfer (W/m2K) |
| Qlat | Latent load, W |
| Ac | Heat transfer area (m2) |
| Hc | Latent heat of condensation (J/kg-K) |
| tr | Room temperature (°C) |
| ma | Mass of the wet air inside the room (kg) |
| tc | Temperature of cold fins (°C) |
| Tsec | Dehumidifying period (sec) |
| Φ1 | Relative humidity before dehumidification (%) |
| Φ2 | Relative humidity after dehumidification (%) |
| kair | Thermal conductivity of air (W/m-K) |
| H | Height of fin (m) |
Appendix

Fig. 5 has presented a double-sided hexagonal slide rule with seven edges for noise measurement representing seven sources of noise. Reference value used for $I_2$ is $-1 \text{ W m}^{-2}$ on positive scale of noise and $1 \text{ W m}^{-2}$ on negative scale of noise. Positive scale of noise has 10 positive units and one negative unit. Whereas, negative scale of noise has 1 positive unit and 10 negative units. Each unit of sol, sip and bel is divided into 11 parts, 1 part is $1/11^{th}$ unit of noise. The base of logarithm used in noise measurement equations is 11. Table 7 has summarized units of noise and their limiting conditions. Table 8 has provided noise calculation charts.

![Fig. 5 A Double-Sided Hexagonal Scales of Noise with Seven Edges (S denotes Sun)](image)

| Grades | Noise Grades and Flag Colors under Limiting Conditions | Noise of Sol | Noise of Scattering | Noise of Elasticity |
|--------|--------------------------------------------------------|--------------|---------------------|-------------------|
| $G_2^* = \pm U$ | No Positive Solar Energy | No Positive Fluid Energy | No Positive Sound Energy |
| $G_1 = G_2 = U$ | Decreasing Solar Energy | Decreasing Fluid Energy | Decreasing Sound Energy |
| Base Color for $G_1 = G_2$ | Increasing Solar Energy | Increasing Fluid Energy | Increasing Sound Energy |
| $G_1 = -U \text{ Wm}^{-2}$ | Negative Solar Energy | Negative Fluid Energy | Negative Sound Energy |
| Base Color for $G_1$ | Darkness | Low Pressure | Inaudible range |
| $G_1 = -\nu$ | Darkness increasing, distance from point source of light increasing | Low pressure increasing, vacuum approaching | Inaudible range increasing, vacuum approaching |
| Base Color for $G_1$ | Decreasing Solar Energy | Decreasing Fluid Energy | Decreasing Sound Energy |
| $G_1 = -U \nu \rightarrow 0 \text{ Wm}^{-2}$ | Negative Solar Energy | Negative Fluid Energy | Negative Sound Energy |
| Base Color for $G_2$ | Decreasing Darkness | Decreasing Low Pressure | Decreasing inaudible range |

a. Reference value of $G_2 = \pm U$ signifies the limiting condition with areas of noise interference approaching to zero.

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| a   | b      | Intensity Ratio (11°) | Pressure Ratio (11°) | →oSol→ | ←oSip→ | ←oBel→ | Pressure Ratio (1/11)b | Intensity Ratio (1/11)a |
|-----|--------|-----------------------|----------------------|--------|--------|--------|------------------------|------------------------|
| 0   | 0      | 1                     | 1                    | 0      | 1      | 1      | 0.897                  | 0.804                  |
| 1/11| 1/22   | 1.244                 | 1.115                | ± 01   | 0.897  | 0.804  | 0.647                  | 0.418                  |
| 2/11| 2/22   | 1.546                 | 1.244                | ± 02   | 0.804  | 0.647  | 0.418                  | 0.270                  |
| 4/11| 4/22   | 2.392                 | 1.546                | ± 04   | 0.647  | 0.418  | 0.270                  | 0.175                  |
| 6/11| 6/22   | 3.699                 | 1.923                | ± 06   | 0.520  | 0.270  | 0.175                  | 0.073                  |
| 8/11| 8/22   | 5.720                 | 2.392                | ± 08   | 0.418  | 0.175  | 0.073                  | 0.031                  |
| 10/11| 10/22  | 8.845                 | 2.974                | ± 10   | 0.336  | 0.113  | 0.073                  | 0.020                  |
| 12/11| 12/22  | 13.679                | 3.699                | ± 12   | 0.270  | 0.073  | 0.031                  | 6.042 x10^-4          |
| 14/11| 14/22  | 21.155                | 4.599                | ± 14   | 0.217  | 0.047  | 6.042 x10^-4          | 9.343 x10^-4          |
| 16/11| 16/22  | 32.715                | 5.720                | ± 16   | 0.175  | 0.031  | 9.343 x10^-4          | 1.445 x10^-3          |
| 18/11| 18/22  | 50.594                | 7.113                | ± 18   | 0.141  | 0.020  | 1.445 x10^-3          | 2.353 x10^-3          |
| 20/11| 20/22  | 78.242                | 8.845                | ± 20   | 0.113  | 0.013  | 2.353 x10^-3          | 3.456 x10^-3          |
| 22/11| 22/22  | 121.000               | 11.000               | ± 22   | 0.091  | 8.264 x10^-3 | 3.456 x10^-3 | 0.073                  |
| 24/11| 24/22  | 187.124               | 13.679               | ± 24   | 0.073  | 5.344 x10^-3 | 3.456 x10^-3 | 0.031                  |
| 26/11| 26/22  | 289.383               | 17.011               | ± 26   | 0.059  | 3.456 x10^-3 | 3.456 x10^-3 | 9.343 x10^-4          |
| 28/11| 28/22  | 447.525               | 21.155               | ± 28   | 0.047  | 2.353 x10^-3 | 3.456 x10^-3 | 1.445 x10^-4          |
| 30/11| 30/22  | 692.089               | 26.308               | ± 30   | 0.038  | 1.445 x10^-4 | 3.456 x10^-3 | 3.907 x10^-4          |
| 32/11| 32/22  | 1070                  | 32.715               | ± 32   | 0.031  | 3.456 x10^-3 | 3.456 x10^-3 | 6.042 x10^-4          |
| 34/11| 34/22  | 1655                  | 40.684               | ± 34   | 0.025  | 6.042 x10^-4 | 3.456 x10^-3 | 3.907 x10^-4          |
| 36/11| 36/22  | 2560                  | 50.594               | ± 36   | 0.020  | 3.907 x10^-4 | 3.907 x10^-4 | 6.042 x10^-4          |
| 38/11| 38/22  | 3959                  | 62.917               | ± 38   | 0.016  | 2.526 x10^-4 | 2.526 x10^-4 | 9.343 x10^-4          |
| 40/11| 40/22  | 6122                  | 78.242               | ± 40   | 0.013  | 1.633 x10^-4 | 2.526 x10^-4 | 6.042 x10^-4          |
| 42/11| 42/22  | 9467                  | 97.300               | ± 42   | 0.010  | 1.056 x10^-4 | 1.056 x10^-4 | 6.042 x10^-4          |
| 44/11| 44/22  | 14640                 | 121.0                | ± 44   | 8.264 x10^-3 | 3.456 x10^-3 | 3.456 x10^-3 | 6.042 x10^-4          |
| 46/11| 46/22  | 22640                 | 150.47               | ± 46   | 6.646 x10^-3 | 6.646 x10^-3 | 3.456 x10^-3 | 6.042 x10^-4          |
| 48/11| 48/22  | 35020                 | 187.12               | ± 48   | 5.344 x10^-3 | 5.344 x10^-3 | 3.456 x10^-3 | 6.042 x10^-4          |
| 50/11| 50/22  | 54150                 | 232.70               | ± 50   | 4.297 x10^-3 | 4.297 x10^-3 | 3.456 x10^-3 | 6.042 x10^-4          |
| 66/11| 66/22  | 1.772 x10^6           | 1331                 | ± 66   | 7.513 x10^-4 | 7.513 x10^-4 | 3.456 x10^-3 | 6.042 x10^-4          |
| 77/11| 77/22  | 1.949 x10^7           | 4414                 | ± 77   | 2.265 x10^-4 | 2.265 x10^-4 | 3.456 x10^-3 | 6.042 x10^-4          |
| 88/11| 88/22  | 2.144 x10^8           | 14640                | ± 88   | 6.830 x10^-5 | 6.830 x10^-5 | 3.456 x10^-3 | 6.042 x10^-4          |
| 99/11| 99/22  | 2.358 x10^9           | 48560                | ± 99   | 2.059 x10^-5 | 2.059 x10^-5 | 3.456 x10^-3 | 6.042 x10^-4          |
| 110/11| 110/22 | 2.594 x10^10          | 161000               | ± 110  | 6.209 x10^-6 | 6.209 x10^-6 | 3.456 x10^-3 | 6.042 x10^-4          |

Example: To find oSol corresponding to a pressure ratio of 363
Ratio of 363 = 11X33
In oSol = +22+32 oSol
= +54 oSol