ANALYSIS OF HEAT TRANSFER FOR BIPV/T MODELS

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OUTLINE OF THE PRESENTATION

Background

Modelling

Case study

Analysis

Conclusion and future work
Solar energy technologies

Photovoltaic (PV) system

Electricity

PV/T system

Electricity & Heat

Thermal (T) collectors

Heat
BIPV/T systems

PV layer

Air channel

Insulated back surface

- Electricity and heat production
- Active cooling of PV modules
- Integration with the building envelope
- Replacement of common building materials
- Aesthetically pleasing look

(Noguchi et al., 2008)
EcoTerra house

- 2.84 kW (electricity) BIPV/T system
- 4 cm air channel of 6.2 m length
- Air temperature rise up to 40°C
JSMB (John Molson School of Business) building

- 300 m² BIPV/T system with 70% covered with PV panels
- 25 kW electricity (20 MWh annually)
- 75 kWth heat for preheating fresh air (55 MWh annually)
Applications

(Yang & Athienitis, 2016)
Growing research interest in BIPV/T systems
Performance prediction with BPS programs

(Nguyen et al., 2014)
MODELING

Thermal network

Energy balance

- Top losses
  - Wind-driven/natural convection
  - Radiation to the surroundings
- Electrical production
- Heat recovery
  - Top channel surface
  - Bottom channel surface
- Back losses
MODELING

TRNSYS/TESS

(Kamel & Fung, 2014)
Type 566: glazed BIPV/T system

Key features

- Temperature uniformity
- Negligible edge heat losses
- Same top and bottom channel convective heat transfer coefficients
- Average Nusselt numbers

(Klein et al., 2018)
MODELING

WARNING

- Circular pipe \( L \equiv D \quad D_h = 4 (\pi D^2 / 4) / \pi D = D \)
- Rectangular duct \( L \equiv D_h = 4A_c / p = 4WH / (2W + 2H) \)

- Circular pipe \( Re = \frac{\rho \bar{v} D_h}{\mu} = \frac{4\rho \bar{v} A_c}{\mu p} = \frac{4\dot{m}_{avg}}{\pi \mu D} \)
- Rectangular duct \( Re = \frac{\rho \bar{v} D_h}{\mu} = \frac{4\rho \bar{v} A_c}{\mu p} = \frac{2\dot{m}_{avg}}{\mu (W + H)} \)

\[ \text{Re} = \frac{2\dot{m}_{avg}}{\mu} \left( \frac{W + H}{\pi WH} \right) \]

\( diameter = 4.*\text{width}*\text{thick\_channel} / (2.*\text{width} + 2.*\text{thick\_channel}) \)

! Calculate the Reynolds number
Reynolds = 4.*\text{flow\_in/pi/diameter}/\text{visc\_air}
BIPV/T experimental set-up (Yang & Athienitis, 2014)

- Small scale version of the BIPV/T roof system in the EcoTerra house
- Amorphous PV module with an electrical efficiency of about 6%
- 5.1 cm of polystyrene insulation 1.76 (K·m²)/W
BIPV/T experimental set-up (Yang & Athienitis, 2014)

<table>
<thead>
<tr>
<th>Information</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel height</td>
<td>0.04 m</td>
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</tr>
<tr>
<td>Channel width</td>
<td>0.38 m</td>
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<tr>
<td>Channel length</td>
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<tr>
<td>Reference electrical efficiency</td>
<td>0.06</td>
<td>-</td>
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<tr>
<td>Average air speed</td>
<td>1.48 m/s</td>
<td></td>
</tr>
<tr>
<td>Average wind speed</td>
<td>1.6 m/s</td>
<td></td>
</tr>
<tr>
<td>Total solar irradiation</td>
<td>1,080 W/m²</td>
<td></td>
</tr>
<tr>
<td>Surroundings temperature</td>
<td>20 °C</td>
<td></td>
</tr>
<tr>
<td>Sky temperature</td>
<td>11 °C</td>
<td></td>
</tr>
</tbody>
</table>
Experimental results (Yang & Athienitis, 2014)
\[
\dot{Q}_{rec} = \dot{Q}_{top} + \dot{Q}_{btm}
\]
\[
\dot{Q}_{btm} = \dot{Q}_{rad} + \dot{Q}_{back}
\]

<table>
<thead>
<tr>
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<tr>
<td>$P_{pv}$</td>
<td>5.5%</td>
</tr>
<tr>
<td>$\dot{Q}_{rad,sky}$</td>
<td>13.6%</td>
</tr>
<tr>
<td>$\dot{Q}_{conv,surr}$</td>
<td>54.9%</td>
</tr>
<tr>
<td>$\dot{Q}_{conv,top}$</td>
<td>24.5%</td>
</tr>
<tr>
<td>$\dot{Q}_{conv,btn}$</td>
<td>1.5%</td>
</tr>
<tr>
<td>$\dot{Q}_{rad}$</td>
<td>1.5%</td>
</tr>
<tr>
<td>$\dot{Q}_{rec}$</td>
<td>26.0%</td>
</tr>
<tr>
<td>$\dot{Q}_{back}$</td>
<td>0%</td>
</tr>
</tbody>
</table>
Local convective heat transfer coefficients

\[ \text{Le} \approx 1.6Dh \text{Re}^{\frac{1}{4}} \]
\[ \text{Le} \approx 1.07 \text{ m} \]

\[ \text{Nu}_{\text{top}}(x) = 8.188 \text{Re}^{0.77} \text{Pr}^{3.85} e^{-x^{0.2}/(2.8Dh)} + 0.061 \text{Re}^{0.77} \text{Pr}^{3.85} \]

\[ \text{Nu}_{\text{btm}}(x) = 4.02 \text{Re}^{1.09} \text{Pr}^{19.3} e^{-x^{0.2}/(14Dh)} + 0.005 \text{Re}^{1.09} \text{Pr}^{19.3} \]
TRNSYS Type 566

- Same average top and bottom channel convective heat transfer coefficients
  
  \[
  \overline{Nu} = 3.66 \quad \text{Laminar flow} \quad 2300 \geq Re
  \]
  
  \[
  \overline{Nu} = 0.023Re^{0.8}Pr^n \quad \text{Turbulent flow} \quad 2300 < Re
  \]
  
  \[
  n = 0.4 \text{ for heating (} T < T_s \text{)}
  \]

- Suggested relationship for wind-driven/natural convection (average value)
  
  \[
  \overline{h}_{\text{conv,surr}} = 5.7 + 3.8\overline{v}_{\text{wind}}
  \]
Experimental validation: Type 566 (modified)
Experimental validation: Type 566 (original)
Previous research studies

![Graph showing heat transfer coefficient vs. distance from inlet]

- $h_{\text{top, cand}}$
- $h_{\text{btm, hegazy}}$
- $h_{\text{btm, yang}}$
- $h_{\text{trnsys}}$
- $\bar{h}_{\text{top, cand}}$
- $\bar{h}_{\text{btm, yang}}$
- $\bar{h}_{\text{btm, hegazy}}$
Experimental validation: Type 566 (original+advice)
MONTHLY RESULTS

- **TRNSYS BIPV/T electrical production**
- **BIPV/T electrical production**
- **TRNSYS BIPV/T heat recovered**
- **BIPV/T heat recovered**

**Electricity production [kWh]**

- January: 10
- February: 8
- March: 12
- April: 10
- May: 12
- June: 15
- July: 20
- August: 30
- September: 25
- October: 20
- November: 15
- December: 10

**Thermal recovery [kWh]**

- January: 5
- February: 7
- March: 10
- April: 8
- May: 10
- June: 12
- July: 15
- August: 20
- September: 16
- October: 12
- November: 10
- December: 7
ANALYSIS

Discussion

Key features (previous studies)

- Length [m]: 2.8 (median) and 3.2 (average)

- Hydraulic diameter [m]: 0.15 (median) and 0.18 (average)

- Average air speed [m/s]:
  - Min: 0.42 (median) and 0.38 (average)
  - Max: 1.7 (median) and 1.5 (average)

- Revised average Nusselt number:
  \[ Nu = Nu_{\infty} (1 + SDh/L) \]
  \[ S = 14.3 \log(L/Dh) - 7.9 \]

  *(Tan & Charters., 1969)*

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- Area: 100 m²
- Width: 6m
- Tilt: 40°
- Roof length: ~ 3.9m
CONCLUSION AND FUTURE WORK

• BIPV/T systems are promising for reducing energy consumption

• BIPV/T models are relatively accurate, but further analyses in terms of heat transfer are required

• Dimensionless correlations for convective heat transfer coefficients are needed (BIPV/T-oriented)
Thank you for listening!

Any questions?
REFERENCES