ANALYSIS OF HEAT TRANSFER FOR BIPV/T MODELS

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OUTLINE OF THE PRESENTATION

Background

Modelling

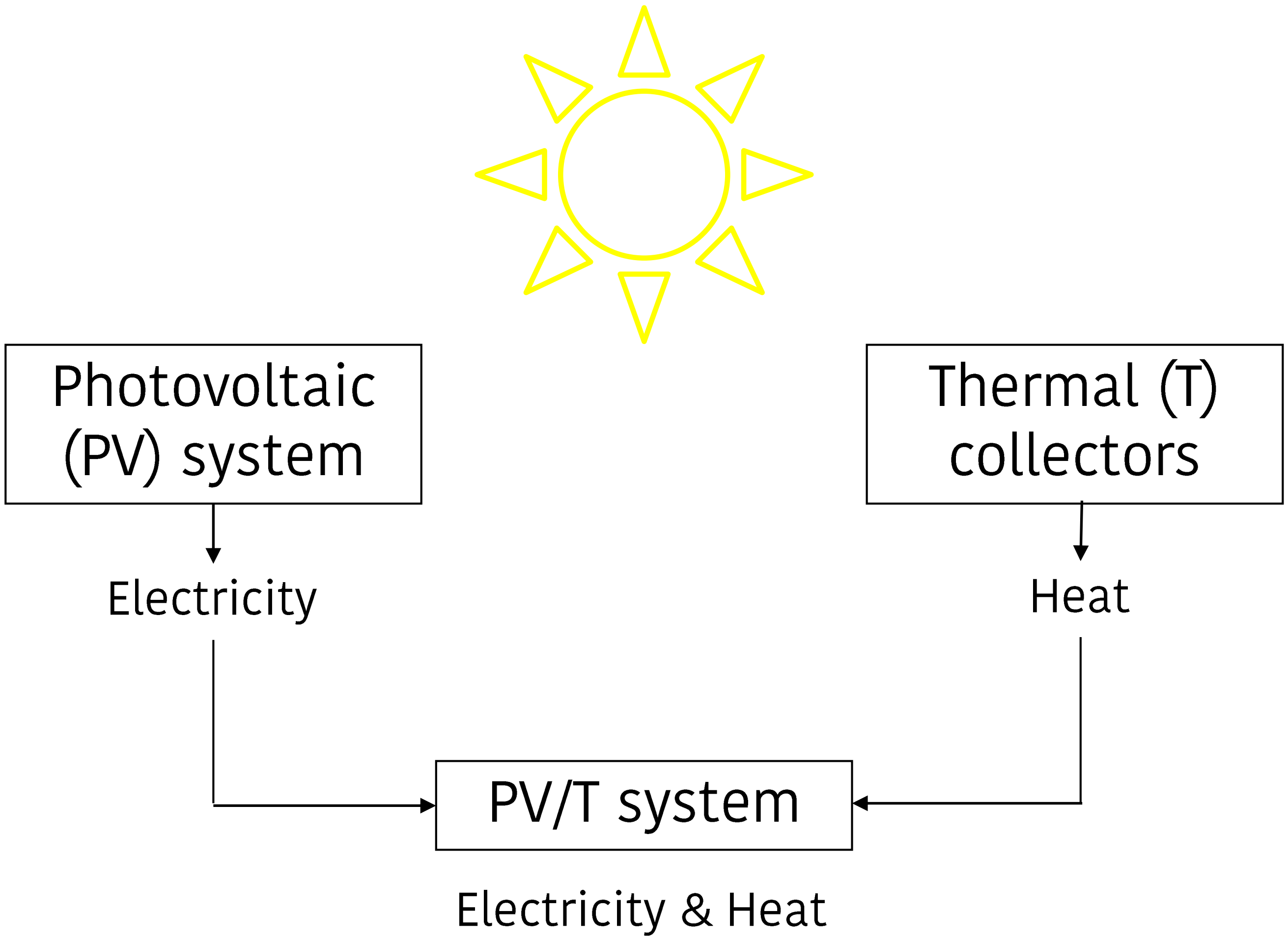
Case study

Analysis

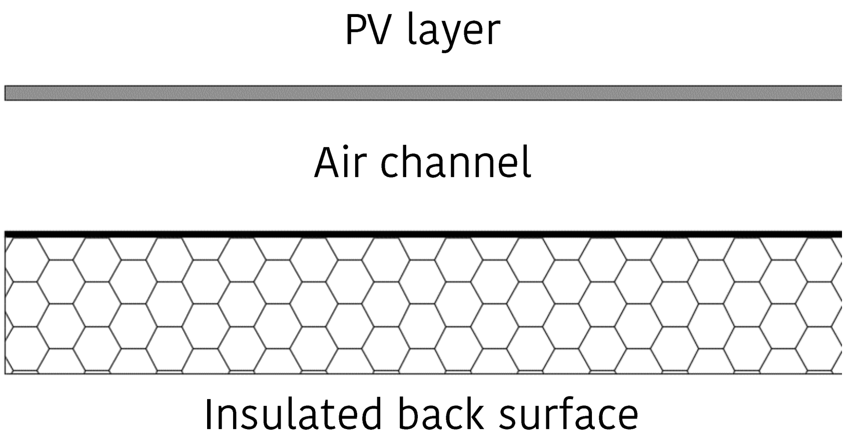
Conclusion and future work

BACKGROUND

Solar energy technologies



BIPV/T systems



(Noguchi et al., 2008)

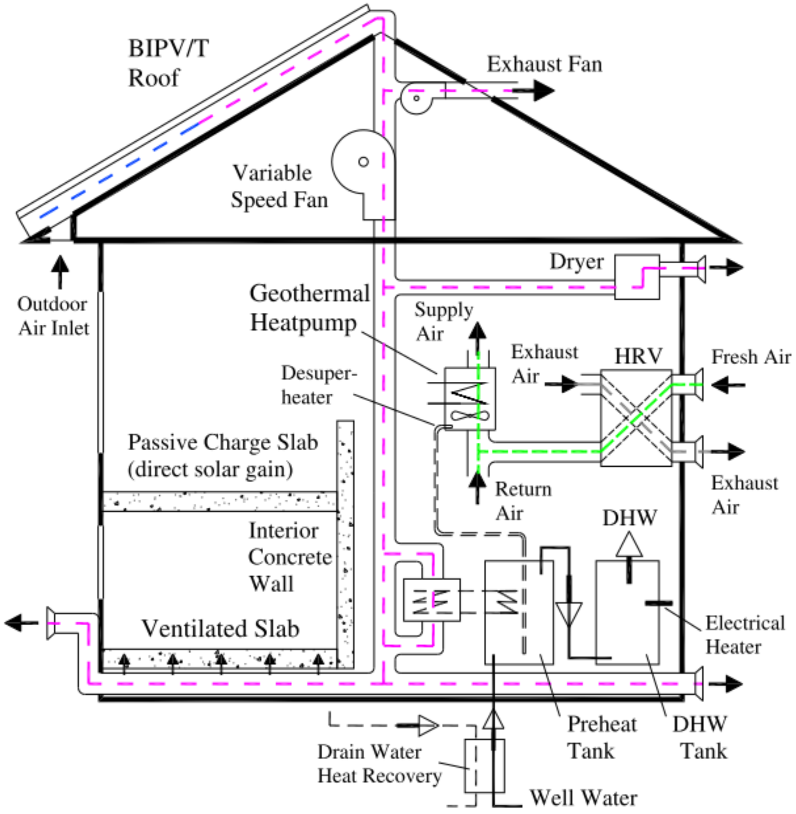
- Electricity and heat production
- Active cooling of PV modules
- Integration with the building envelope
- Replacement of common building materials
- Aesthetically pleasing look

BACKGROUND

EcoTerra house

(Chen et al., 2010)

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



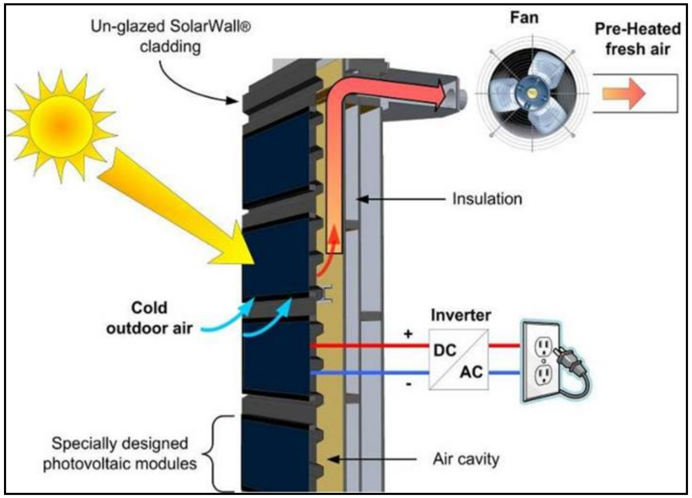
(Chen et al., 2010)

BACKGROUND

JSMB (John Molson School of Business) building

(CZEBS, 2018)

(CZEBS, 2018)

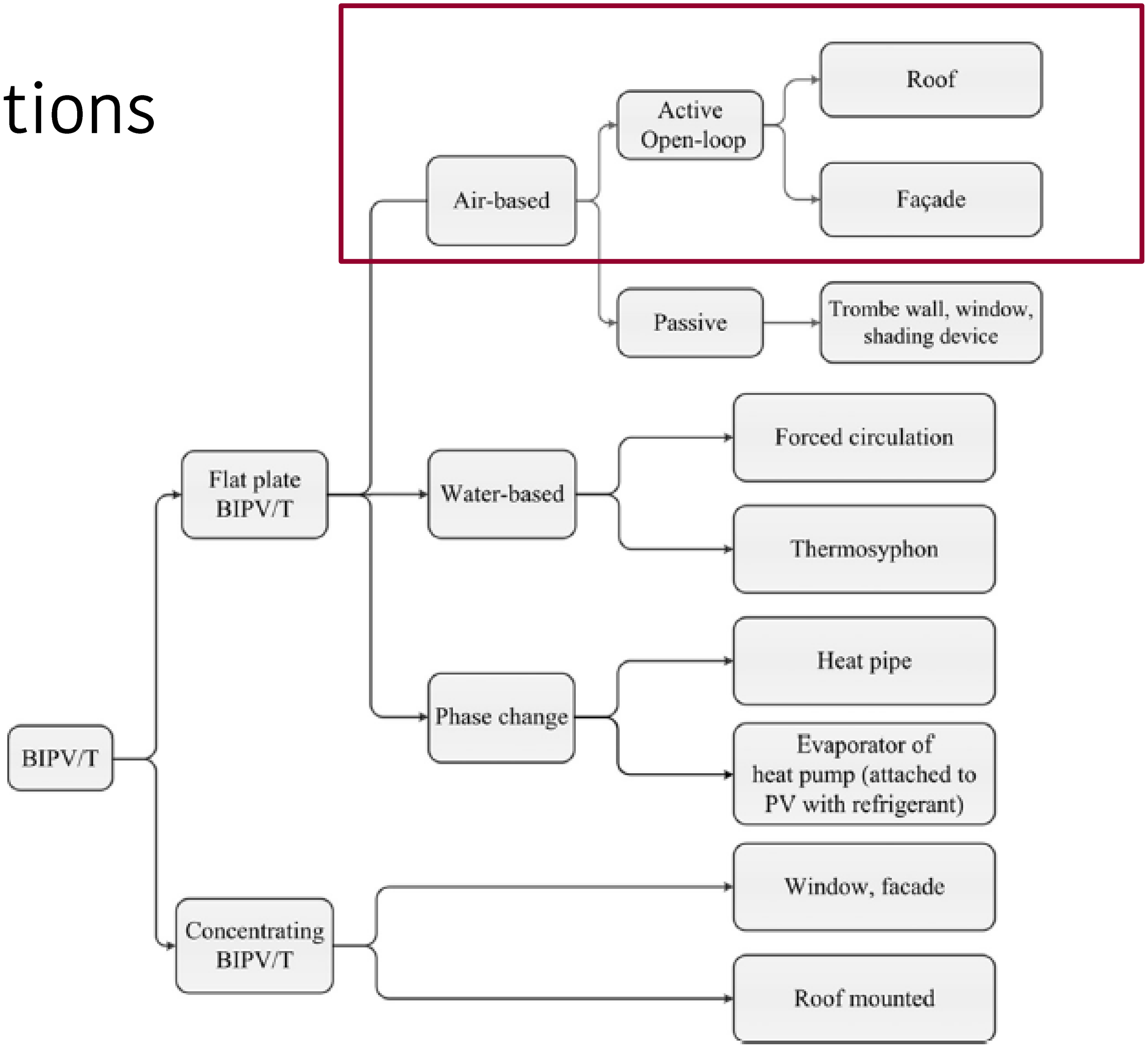


(CZEBS, 2018)

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

BACKGROUND

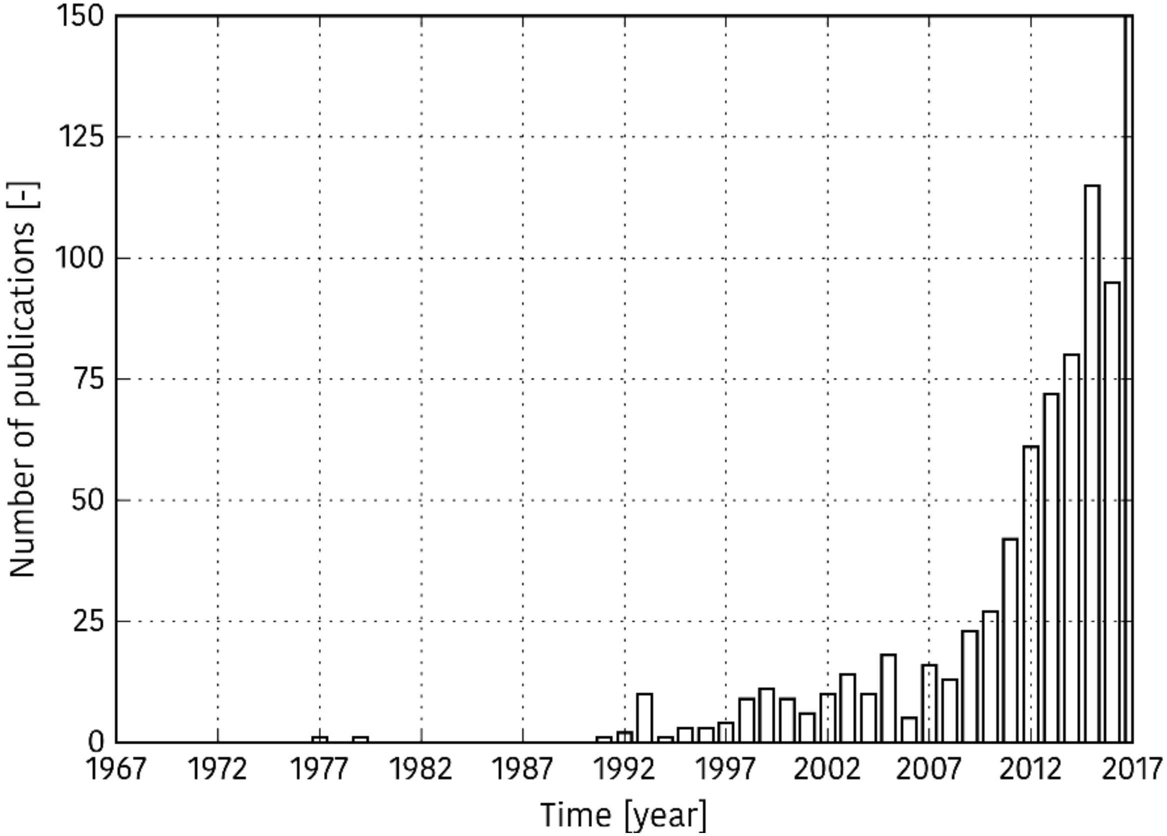
Applications



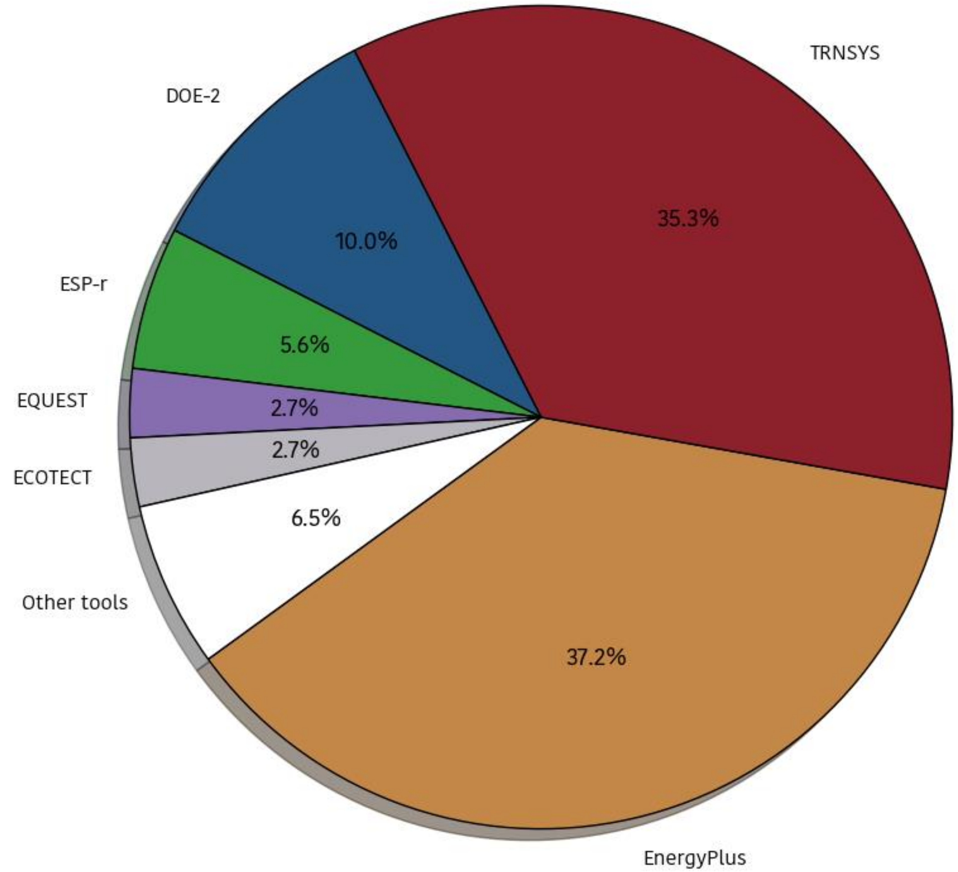
(Yang & Athienitis, 2016)

BACKGROUND

Growing research interest in BIPV/T systems

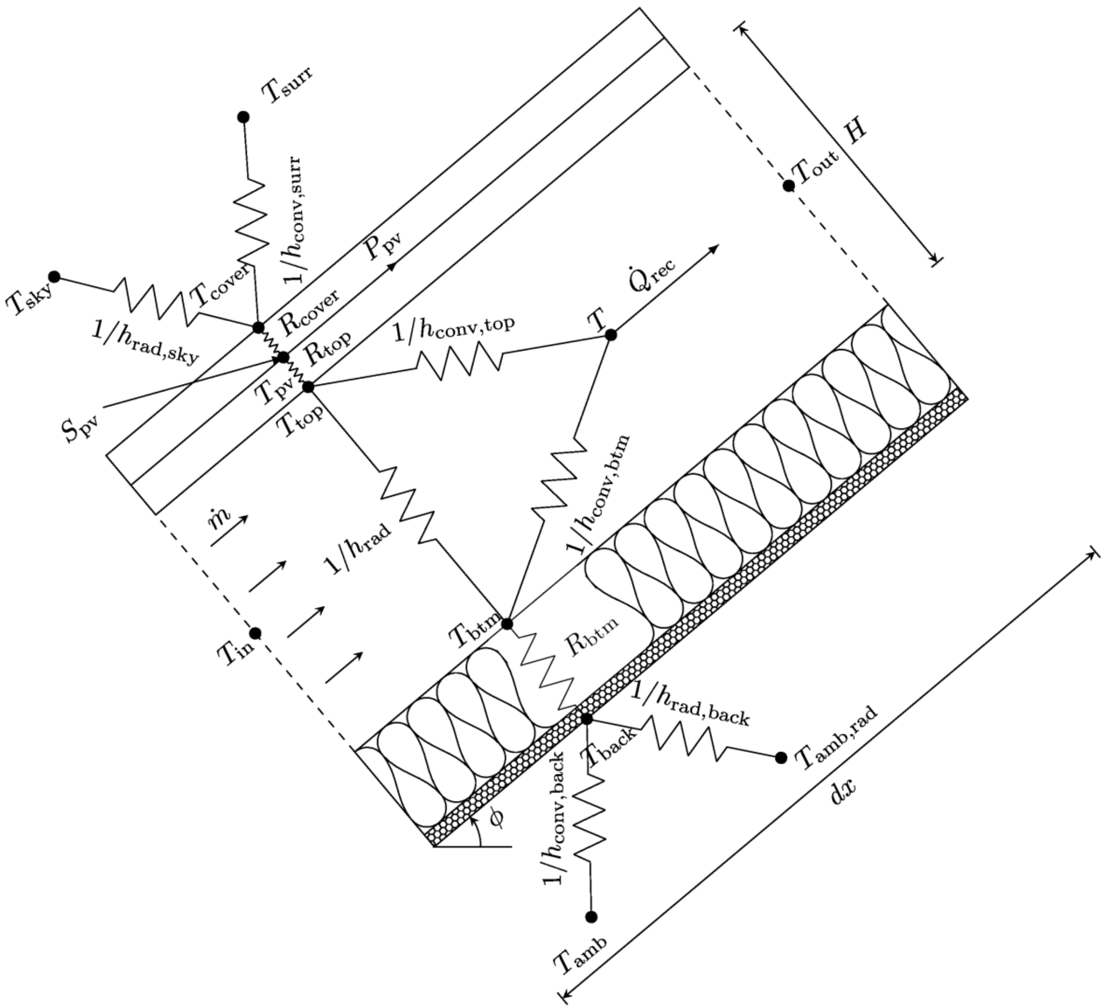


Performance prediction with BPS programs



(Nguyen et al., 2014)

Thermal network

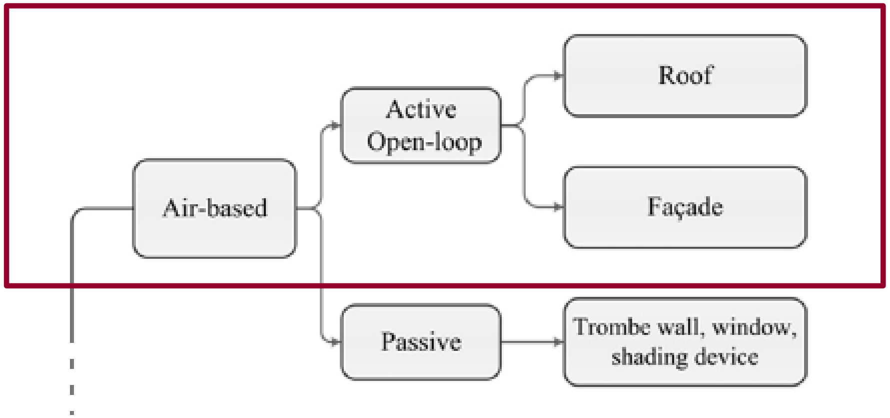


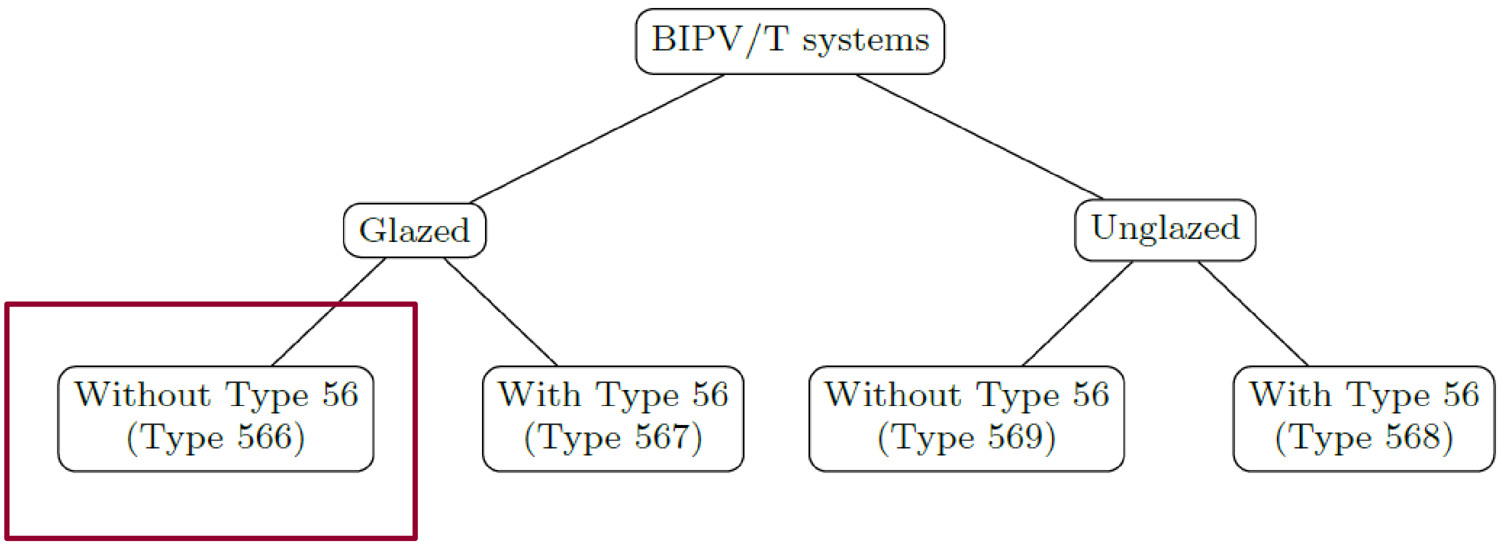
Energy balance

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

MODELING

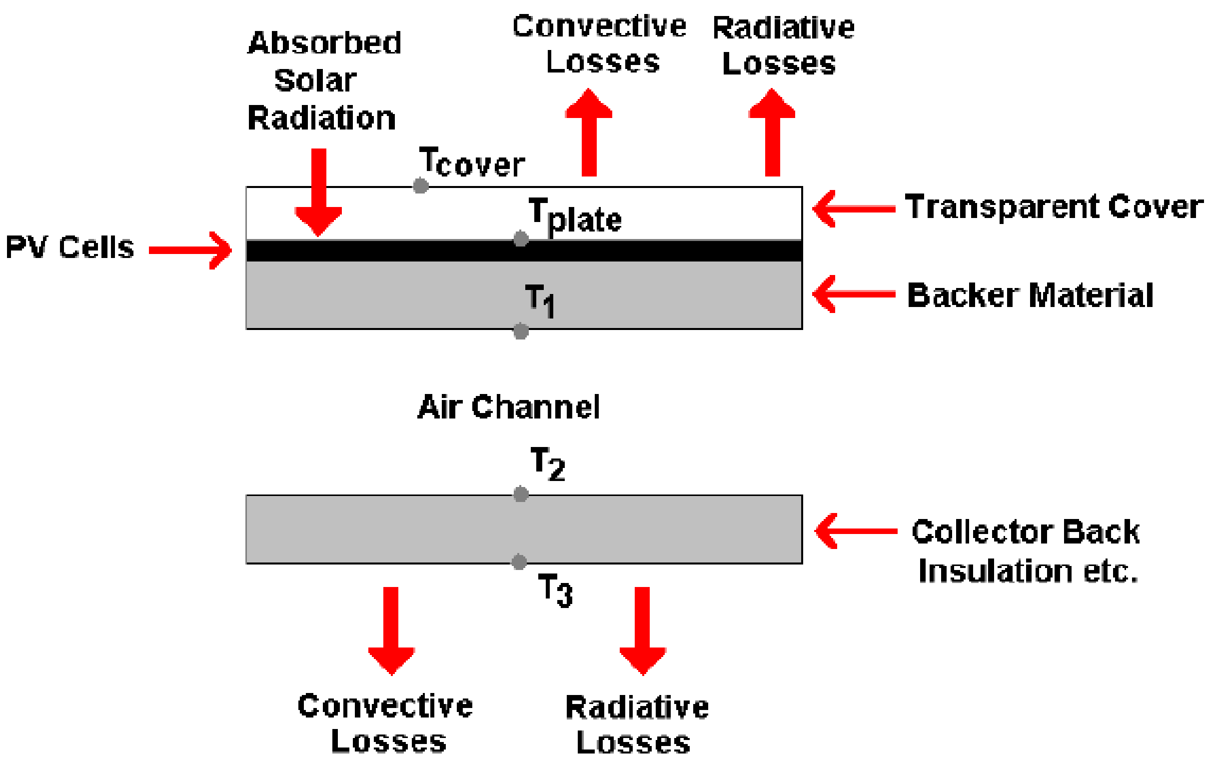
TRNSYS/TESS





(Kamel & Fung, 2014)

Type 566: glazed BIPV/T system



(Klein et al., 2018)

Key features

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

MODELING

WARNING

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

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

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 diameter = 4.*width*thick_channel/(2.*width+2.*thick_channel)

! Calculate the Reynolds number
 Reynolds = 4.*flow_in/pi/diameter/visc_air
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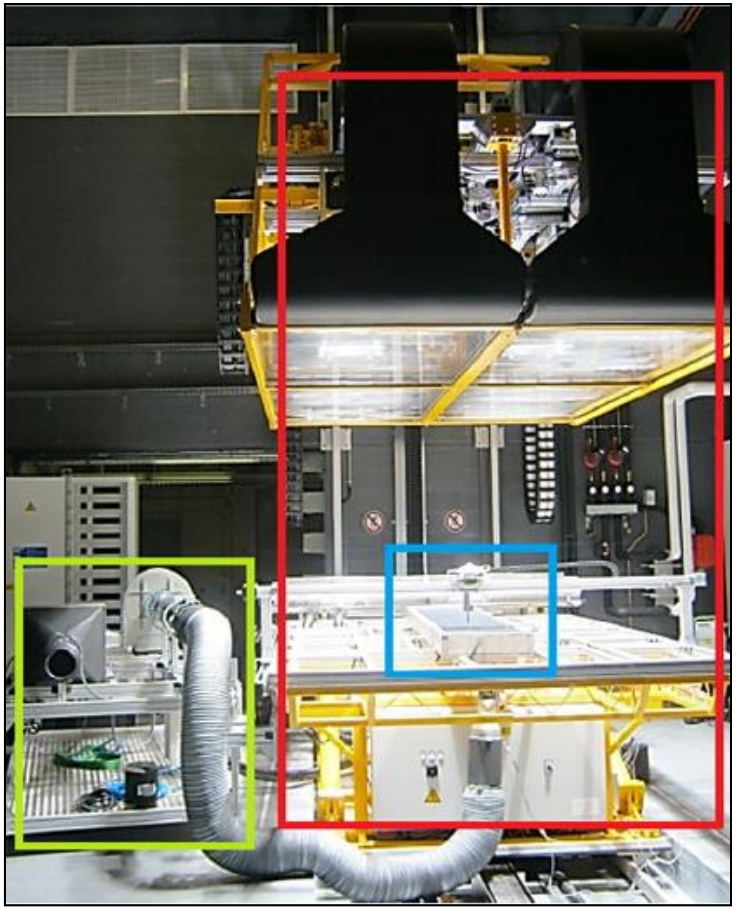
$$Re = \frac{2\dot{m}_{avg}}{\mu}\left(\frac{W + H}{\pi WH}\right)$$

CASE STUDY

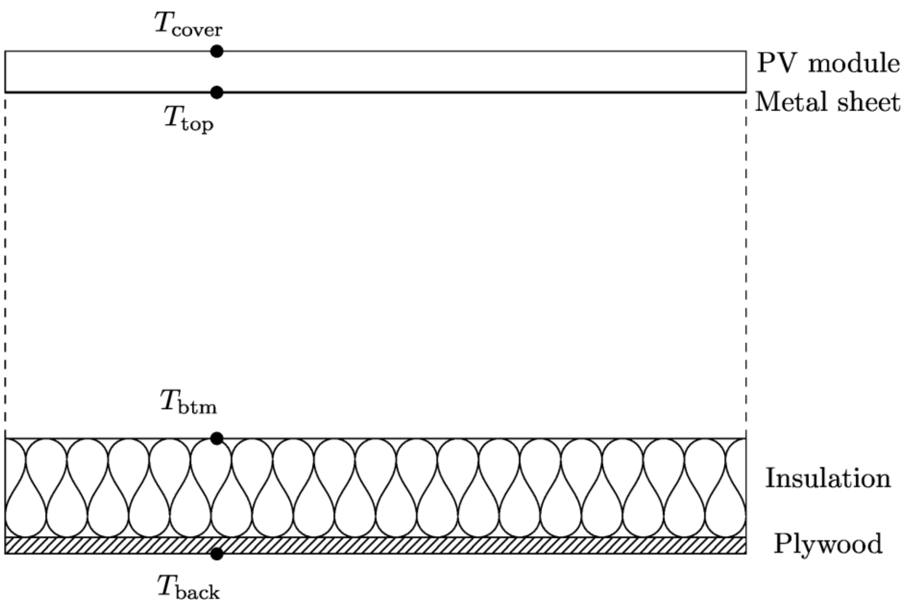
BIPV/T experimental set-up (Yang & Athienitis, 2014)



- 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 $(K \cdot m^2)/W$

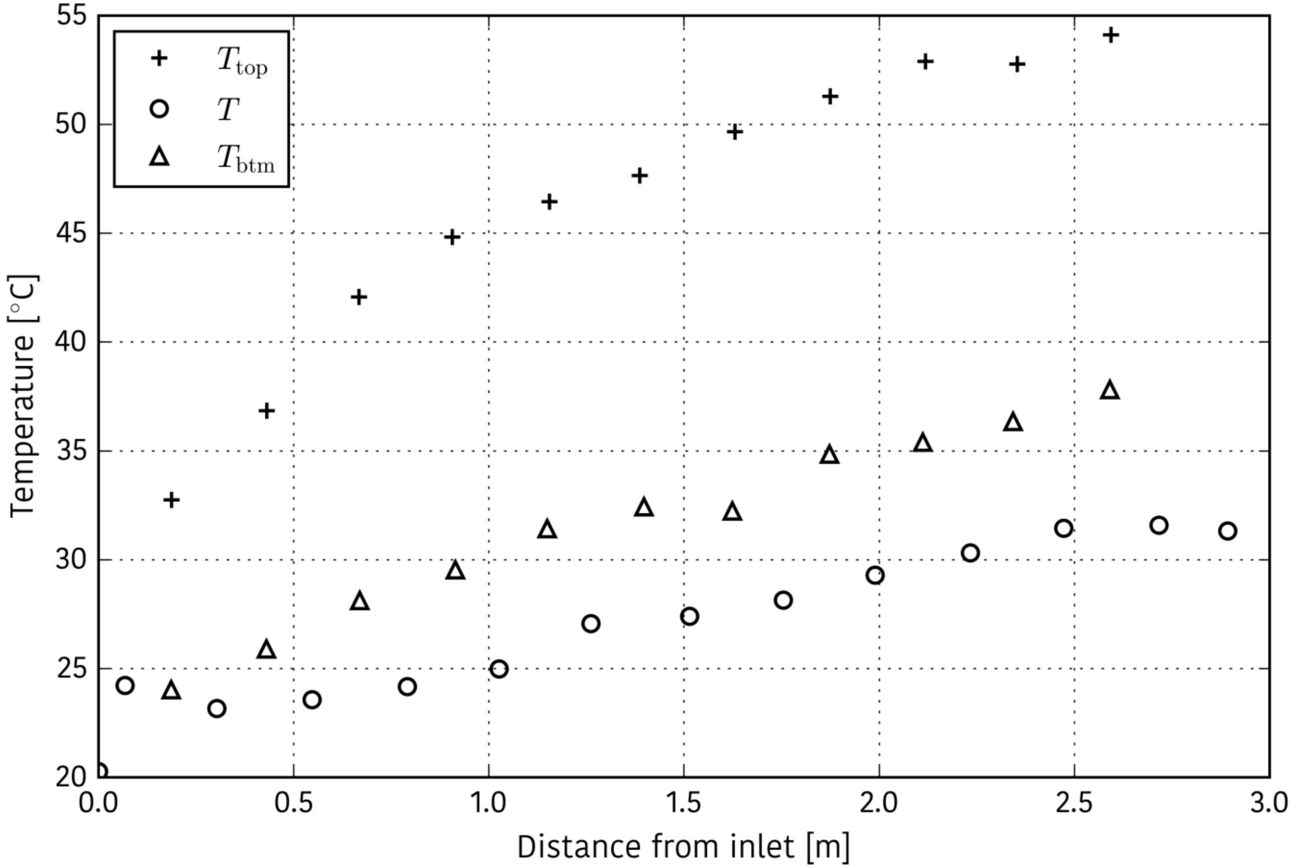
CASE STUDY

BIPV/T experimental set-up (Yang & Athienitis, 2014)

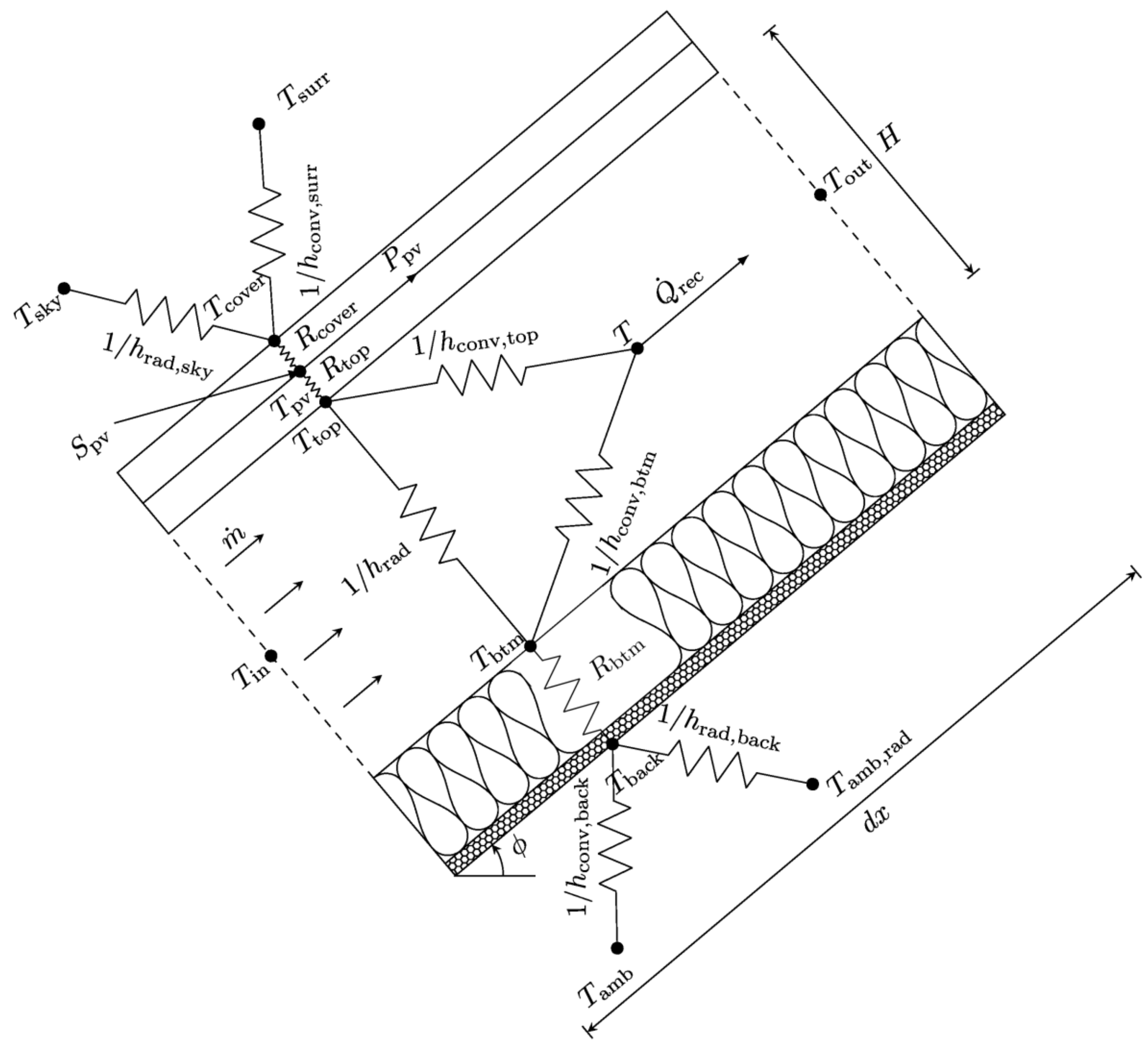


Information	**Value**	**Unit**
Channel height	0.04	m
Channel width	0.38	m
Channel length	2.89	m
Reference electrical efficiency	0.06	-
Average air speed	1.48	m/s
Average wind speed	1.6	m/s
Total solar irradiation	1,080	W/m^2
Surroundings temperature	20	°C
Sky temperature	11	°C

Experimental results (Yang & Athienitis, 2014)



CASE STUDY



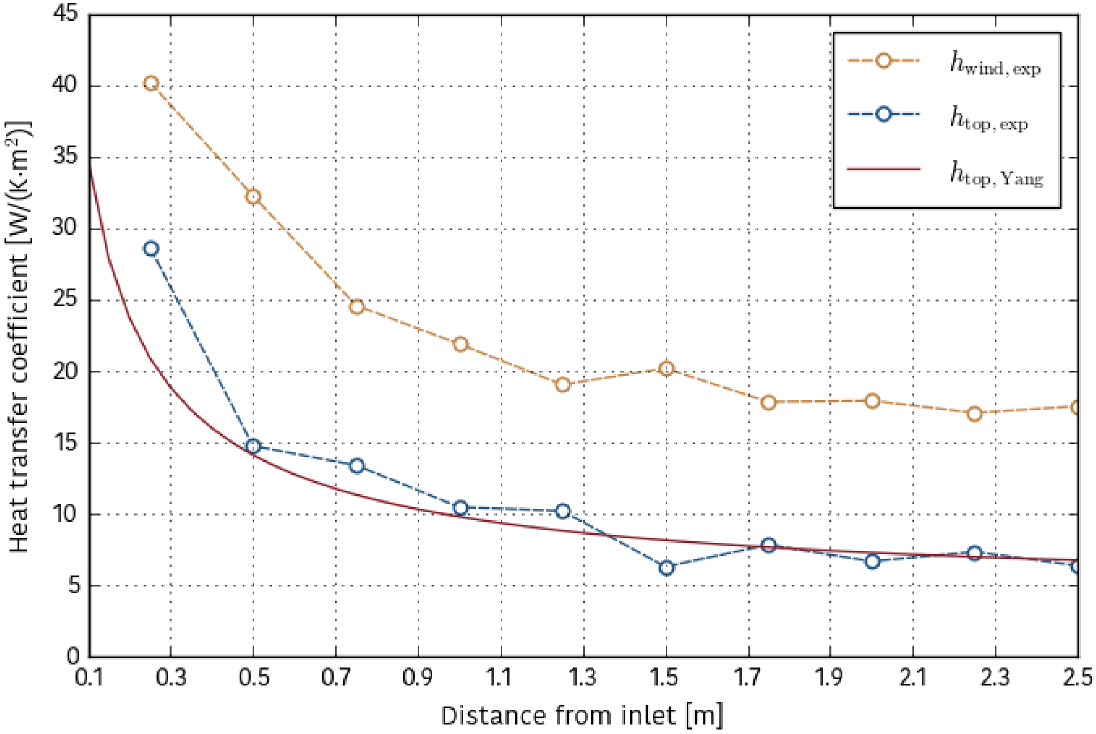
$$\dot{Q}_{rec} = \dot{Q}_{top} + \dot{Q}_{btm}$$
$$\dot{Q}_{btm} = \dot{Q}_{rad} + \dot{Q}_{back}$$

⋮

Energy balance	**Value**
$\boldsymbol{P}_{\mathbf{pv}}$	5.5%
$\dot{\boldsymbol{Q}}_{\mathbf{rad,sky}}$	13.6%
$\dot{\boldsymbol{Q}}_{\mathbf{conv,surr}}$	54.9%
$\dot{Q}_{\mathrm{conv,top}}$	24.5%
$\dot{Q}_{\mathrm{conv,btm}}$	1.5%
$\dot{Q}_{\mathrm{rad}}$	1.5%
$\dot{\boldsymbol{Q}}_{\mathbf{rec}}$	26.0%
$\dot{\boldsymbol{Q}}_{\mathbf{back}}$	0%

CASE STUDY

Local convective heat transfer coefficients



$L_e \approx 1.6DhRe^{1/4}$

$L_e \approx 1.07$ m

$$Nu_{top}(x) = 8.188Re^{0.77}\mathrm{Pr}^{3.85}e^{-x^{0.2}/(2.8Dh)} + 0.061Re^{0.77}\mathrm{Pr}^{3.85}$$

Turbulent flow

$2300 < Re < 9500$

$$Nu_{btm}(x) = 4.02Re^{1.09}\mathrm{Pr}^{19.3}e^{-x^{0.2}/(14Dh)} + 0.005Re^{1.09}\mathrm{Pr}^{19.3}$$

ANALYSIS

TRNSYS Type 566

- Same average top and bottom channel convective heat transfer coefficients

$$\overline{Nu} = 3.66$$ Laminar flow $2300 \geq Re$

$$\overline{Nu} = 0.023Re^{0.8}Pr^{n}$$ Turbulent flow $2300 < Re$

$n = 0.4$ for heating $(T < T_s)$

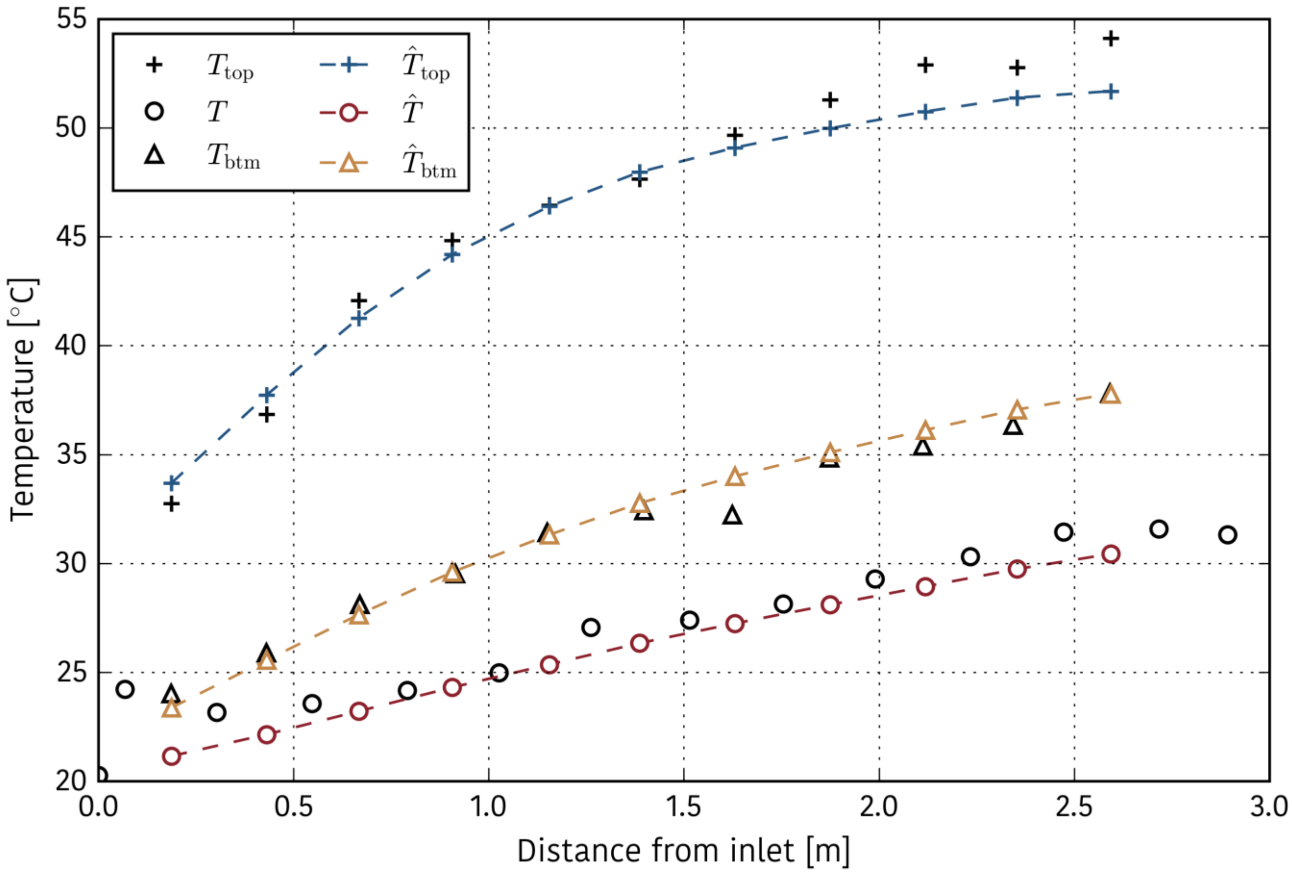
$$\bar{h}_{\text{conv,top}} = \bar{h}_{conv,\text{btm}} = \frac{\overline{Nu}\, k}{Dh}$$

- Suggested relationship for wind-driven/natural convection (average value)

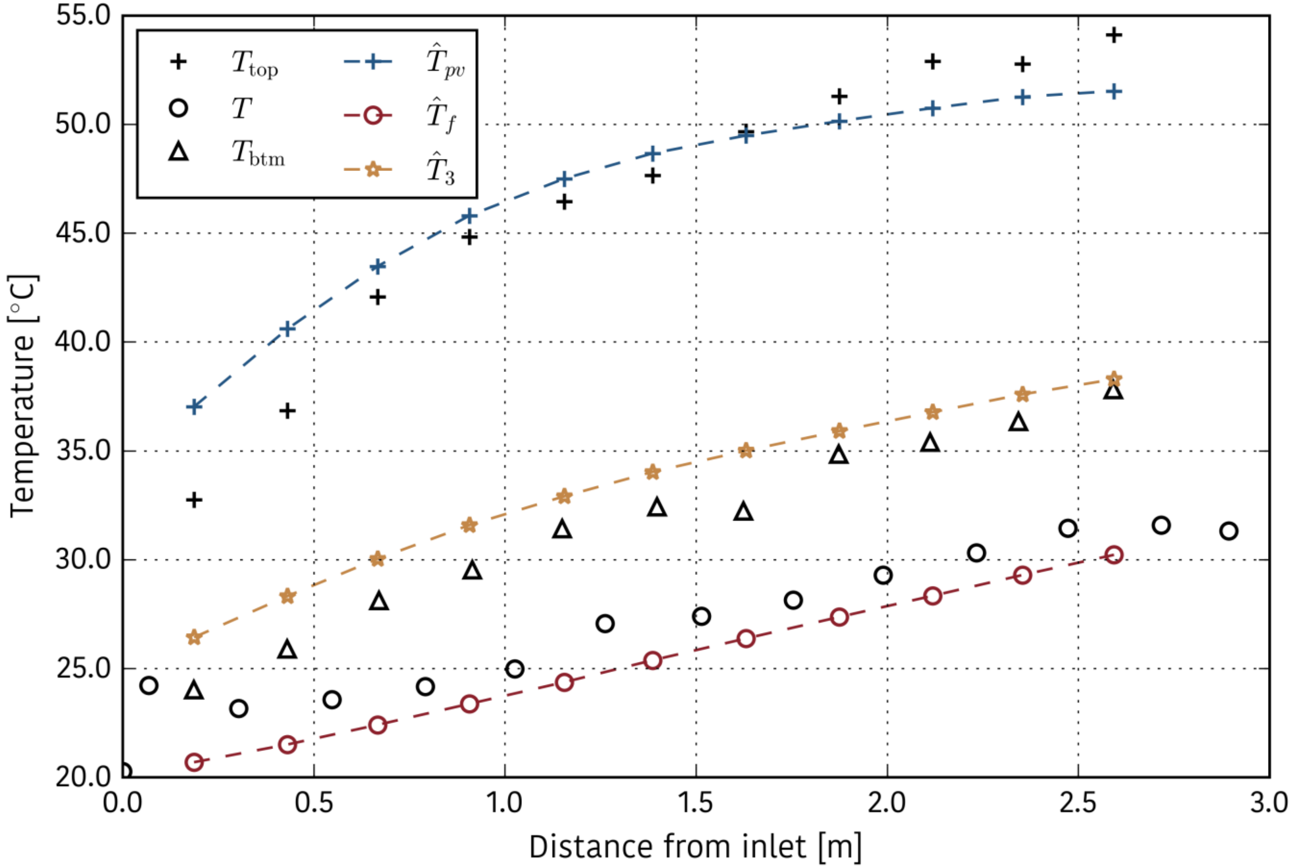
$$\bar{h}_{\text{conv,surr}} = 5.7 + 3.8\bar{v}_{\text{wind}}$$

ANALYSIS

Experimental validation: Type 566 (modified)

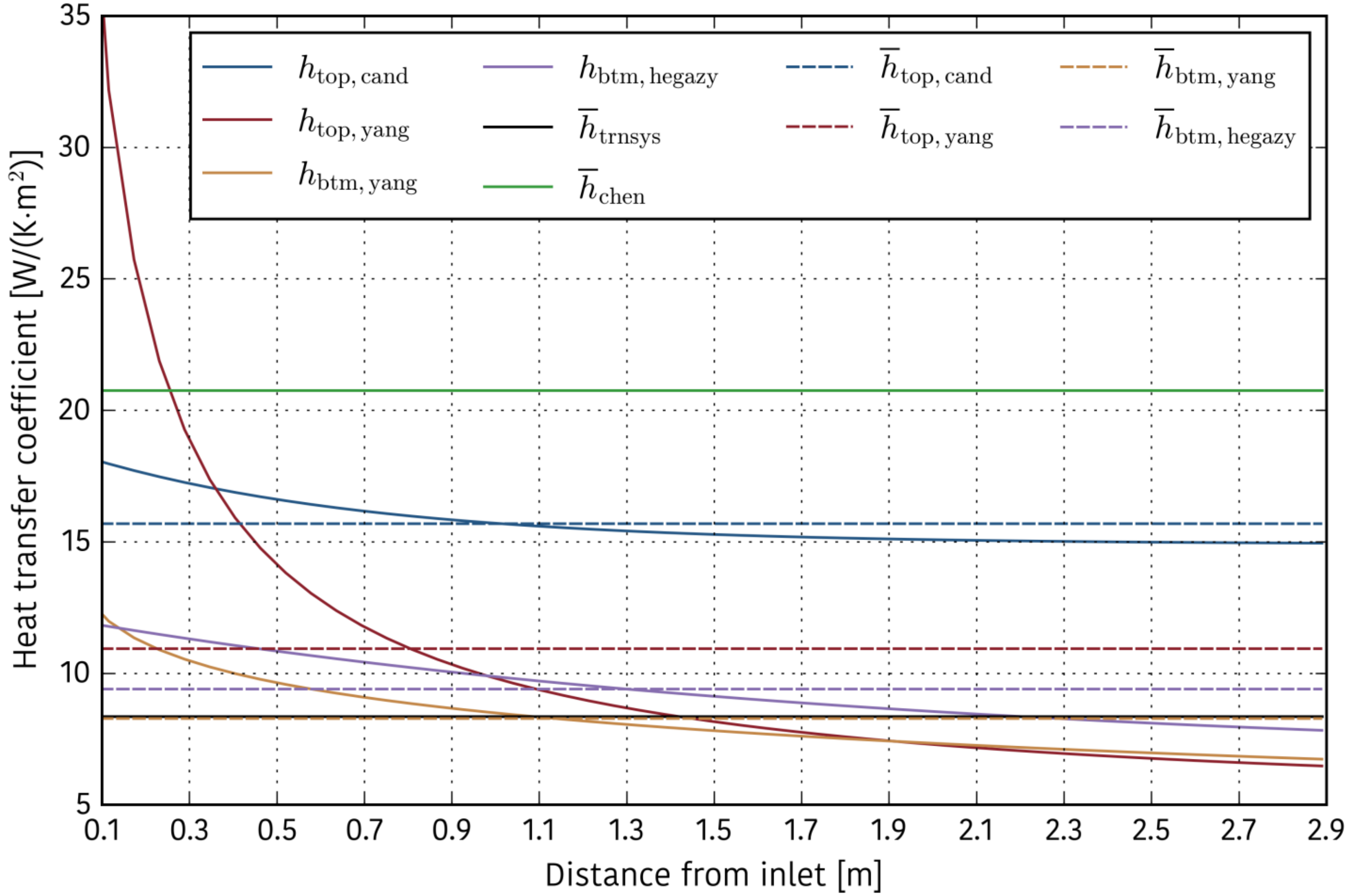


Experimental validation: Type 566 (original)

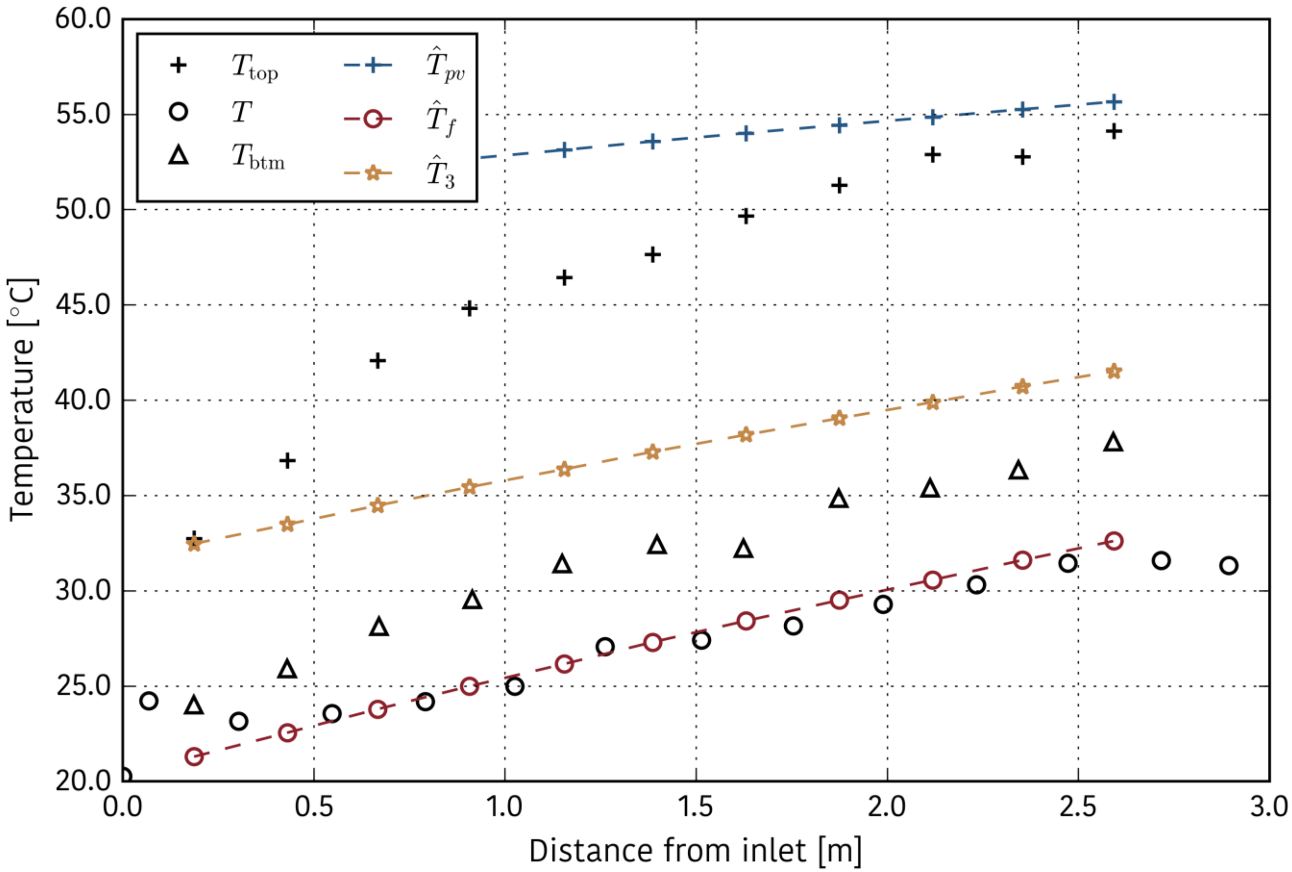


ANALYSIS

Previous research studies

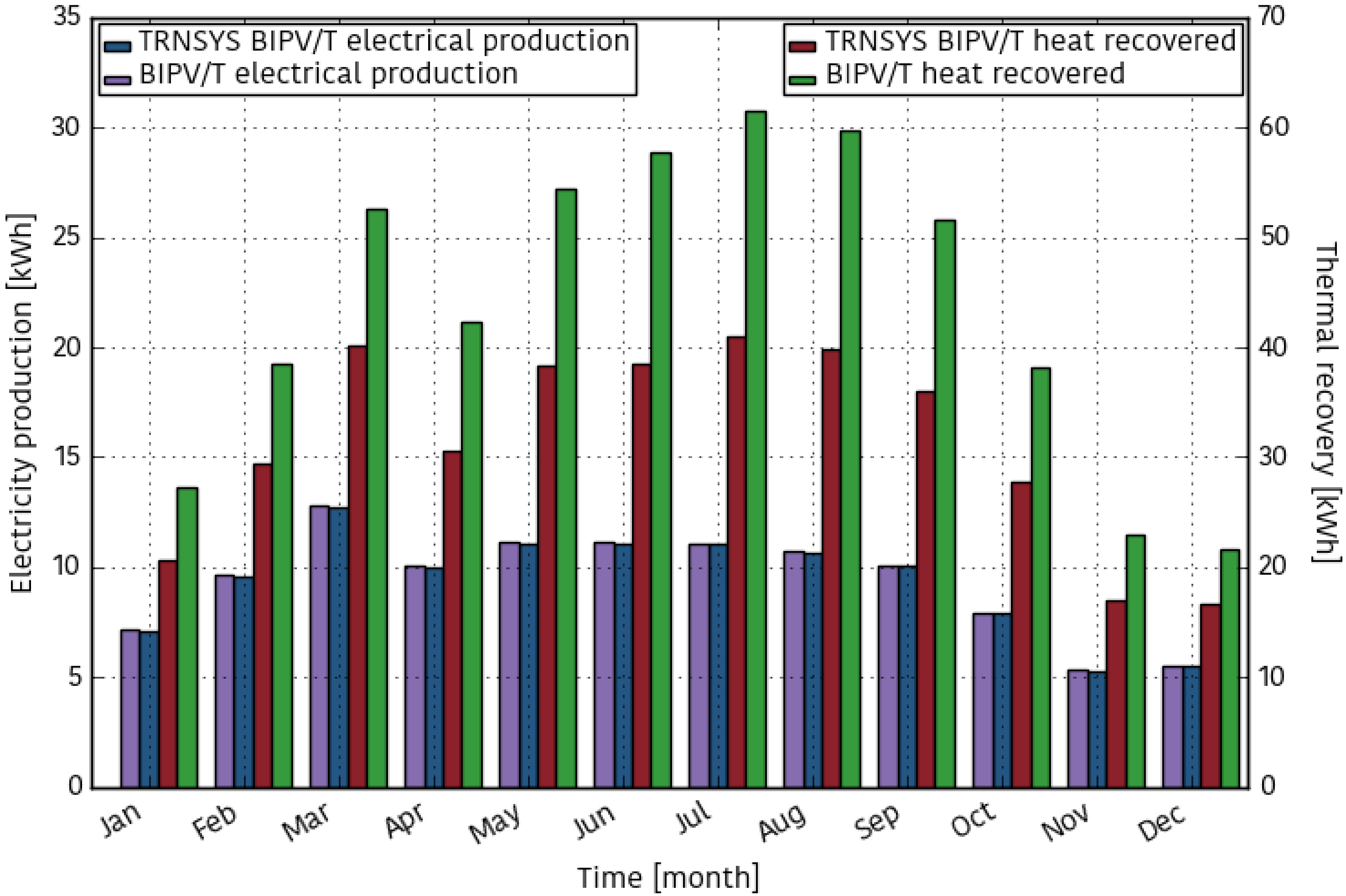


Experimental validation: Type 566 (original+advice)



ANALYSIS

Monthly results



Discussion

Information	Value	Unit
Channel length	2.89	m
Hydraulic diameter	0.073	m
Average air speed	1.48	m/s

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)

- Area: 100 m^2
- 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)

END OF THE PRESENTATION

Thank you for listening!

Any questions?

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