Residential Building Energy Efficiency Meeting 2010
Denver, CO
July 20-22, 2010

Modeling, Testing, and Evaluation of Building-Integrated Photovoltaic-Thermal Collectors

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Acknowledgments

- University of Colorado
  - Ross Casey
  - Chad Corbin
  - Noble Lilliestierna
  - James Zdrowski
  - John Zhai
- NREL
  - Jay Burch
  - Tim Merrigan
- PVT Solar
- DOE
- ASHRAE

Outline

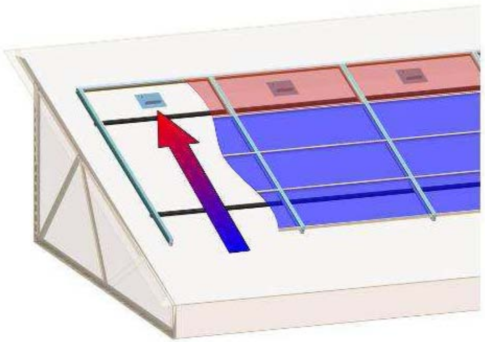
- Introduction
  - Overview of BIPV/T
  - PV/T Systems Evaluated
  - Modeling
- Experimental Testing
  - Air Collector
  - Liquid Collector
  - Proof-of-Concept Prototype
- Simulation Results
  - Air Collector
  - Liquid Collector
- Conclusions
  - Observations
  - Gaps and Barriers

Introduction
Overview of BIPV/T

- BIPV/T collectors combine thermal and electrical collection into a single unit
  - Smaller overall rooftop area
  - Incremental cost can be low
  - Heat collection can increase electrical performance
  - Building integration reduces cost by replacing materials
- Applications:
  - Domestic hot water (DHW)
  - Hydronic or air space heating
  - Ventilation air pre-heat
  - Heat pump assist
  - Night cooling

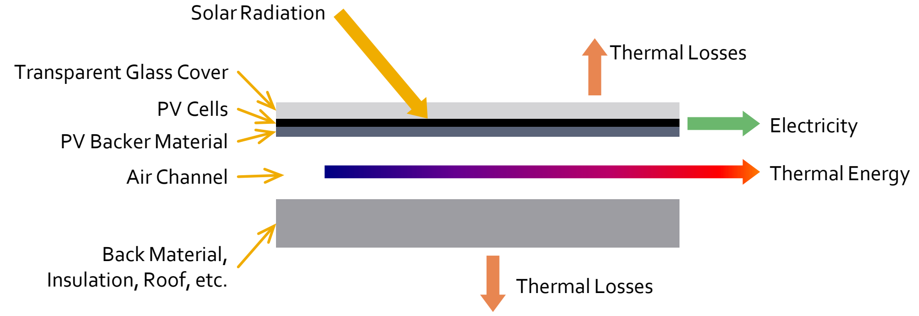
Introduction
PV/T Systems Evaluated

- Air Collector
  - Outdoor air drawn behind PV modules
  - Glazed air collector gives final thermal boost
- Liquid Retrofit
  - Water/glycol circulated in finned tubes mounted on roof behind PV modules
- Liquid Mat Prototype
  - EPDM tube mat attached to back of PV

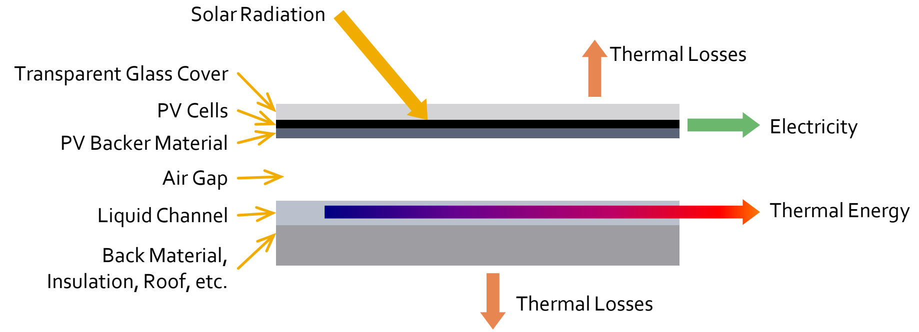


Introduction
PV/T Systems Evaluated

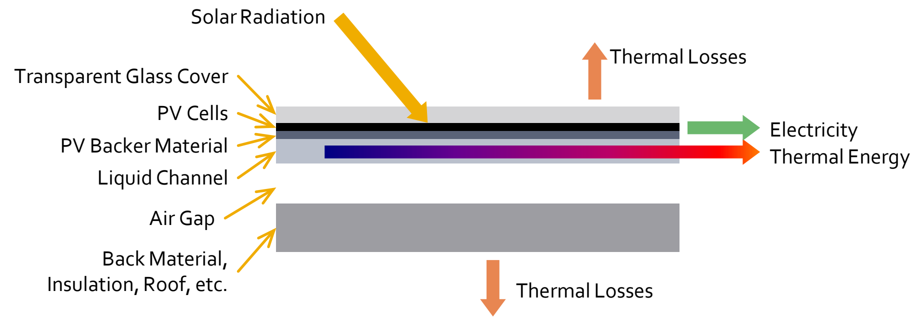
- Air Collector



- Liquid Retrofit

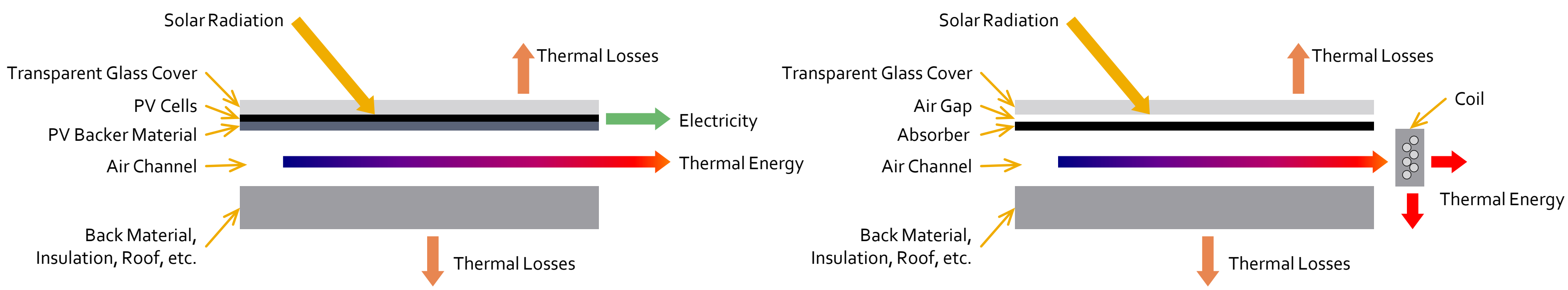


- Liquid Mat Prototype



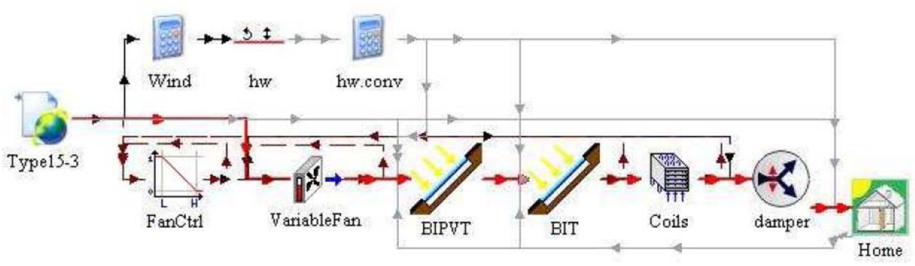
Introduction
PV/T Systems Evaluated

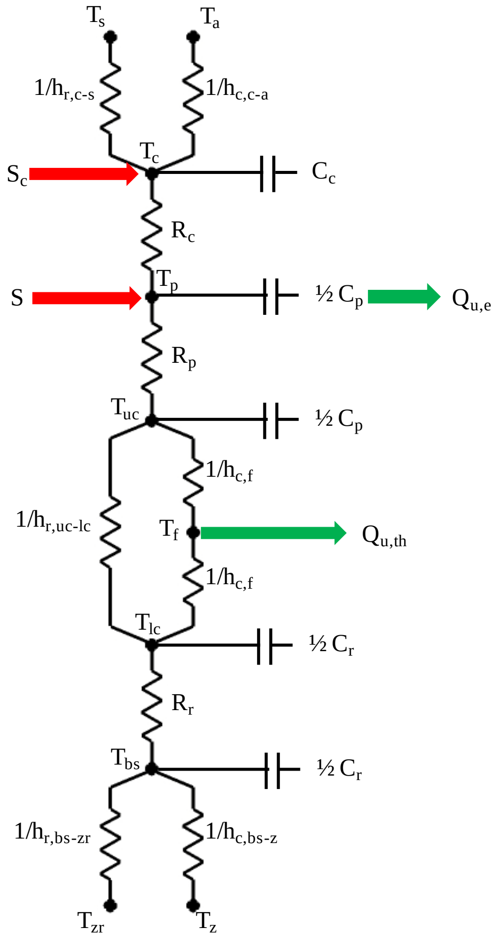
- Air PV/T Collector with Thermal Boost
  - Begin by drawing outdoor air behind PV modules
  - Final thermal boost with glazed air solar collector



Introduction
Modeling

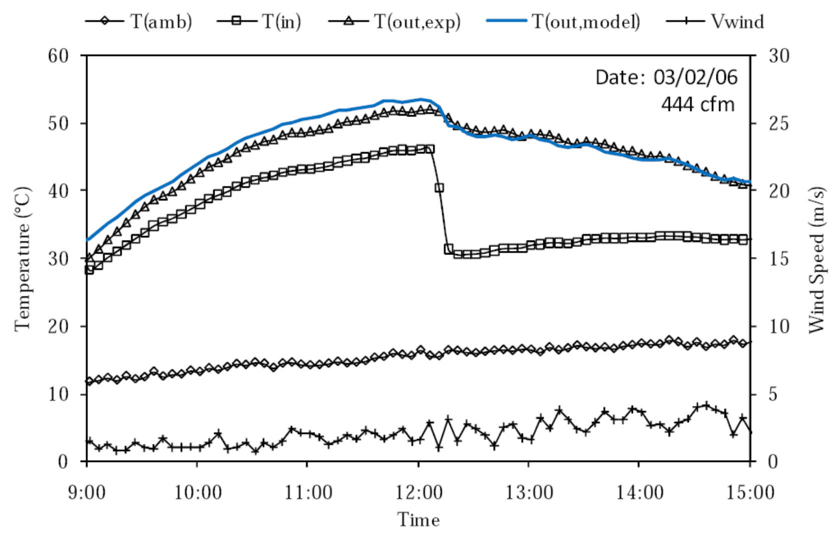
- Detailed first-principles models
- Implemented in MATLAB or TRNSYS





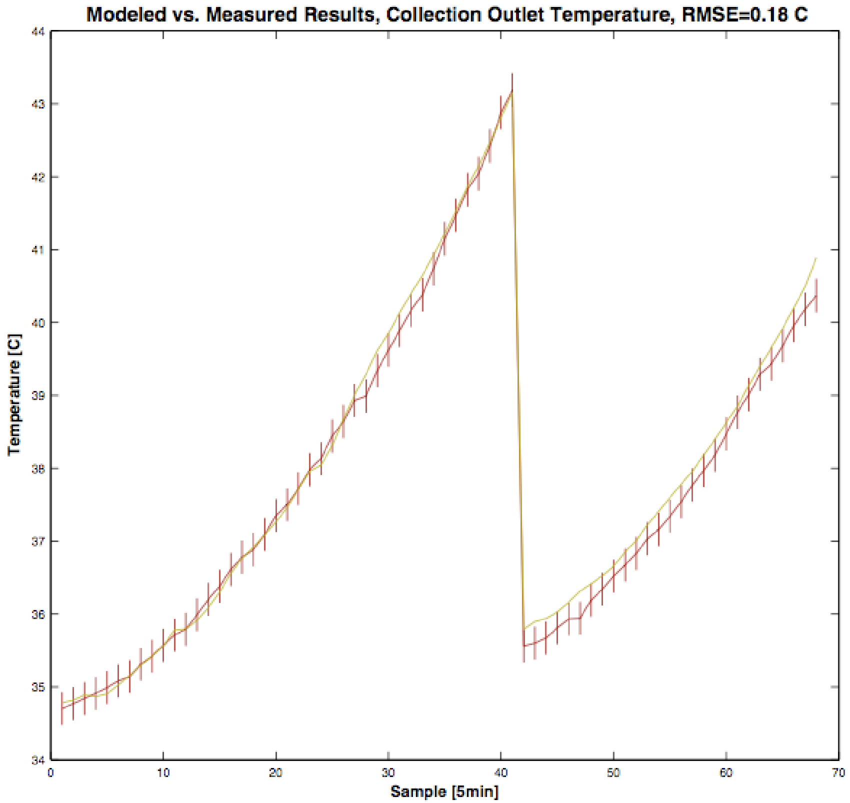
Experimental Testing
Air PV/T with Thermal Boost

- Testing performed by manufacturer in 2006
  - PV/T only
  - PV/T with boost
- Model validated with test data
- Model used for annual energy analysis



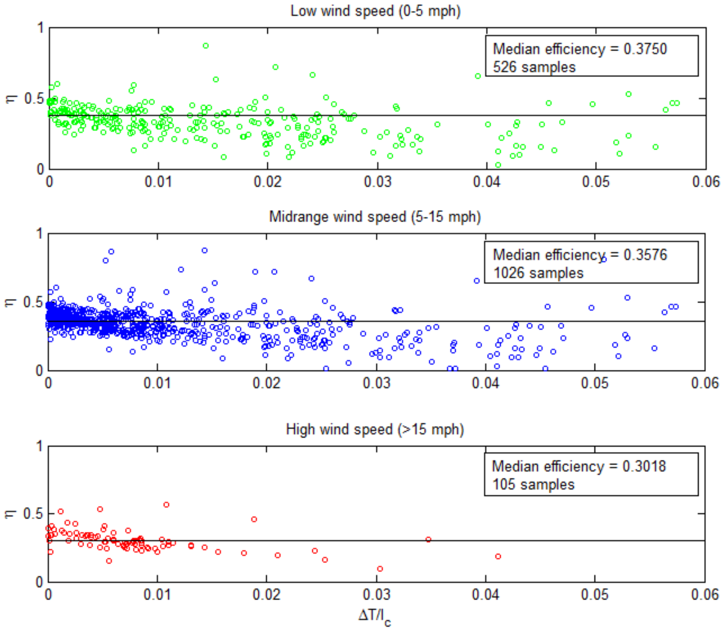
Experimental Testing
Liquid Retrofit PV/T

- Testing on 2007 Colorado Solar Decathlon house
  - Heat collection
  - Heat rejection
- Model validated with test data
- Model used for parametric analysis



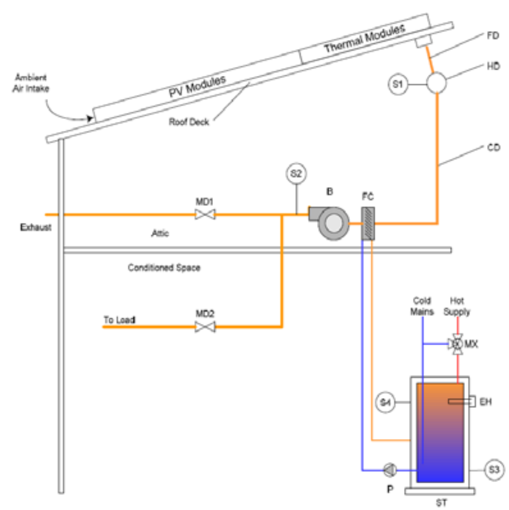
Experimental Testing Liquid Mat Prototype

- Testing on prototype product
  - ASHRAE student project
  - Proof of concept
- Preliminary performance



Simulation Results
Air PV/T with Thermal Boost

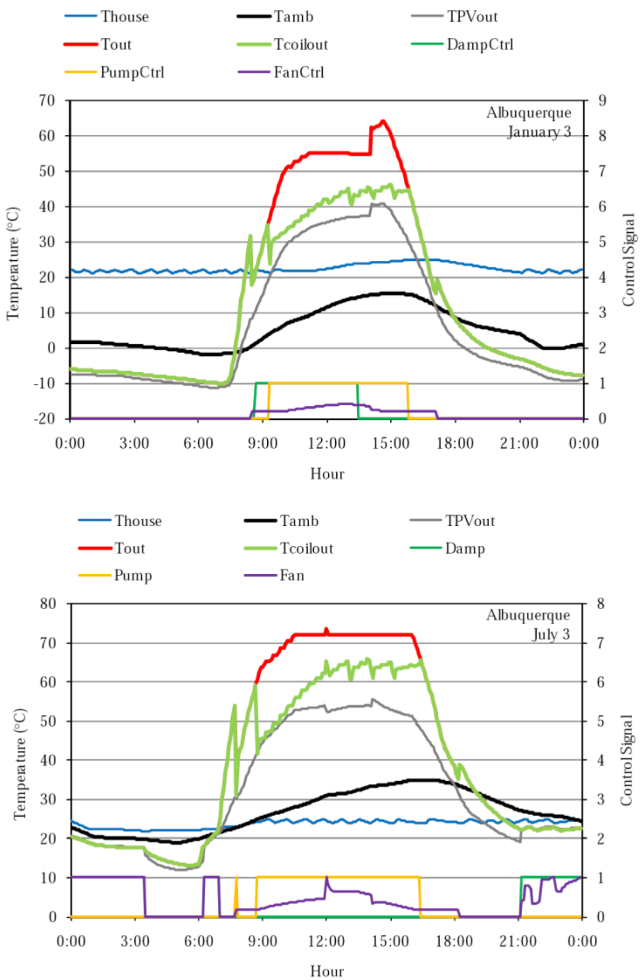
- Baseline: 4 kW roof mounted PV system
- Add PV/T
- Add glazed thermal collectors by removing PV (area constrained)
- Site and source energy
  - DHW
  - Space heating
  - Night cooling
- Seven climates



PART	DESCRIPTION
B	Fan / Blower
CD	Common Duct
EH	Electric Element Heater
FC	Hydronic Fan Coil
FD	Flexible Connection Duct
HD	Header Duct
MD	Motorized Damper
MX	Mixing Valve
P	Pump
S	Temperature Sensor
ST	Water Storage Tank

Simulation Results
Air PV/T with Thermal Boost

- Typical daily operating profiles – January and July
- Control fan speed to maintain leaving temperature setpoint
- Leaving temperature setpoint depends on outdoor air temperature
- Pump operates to preheat DHW

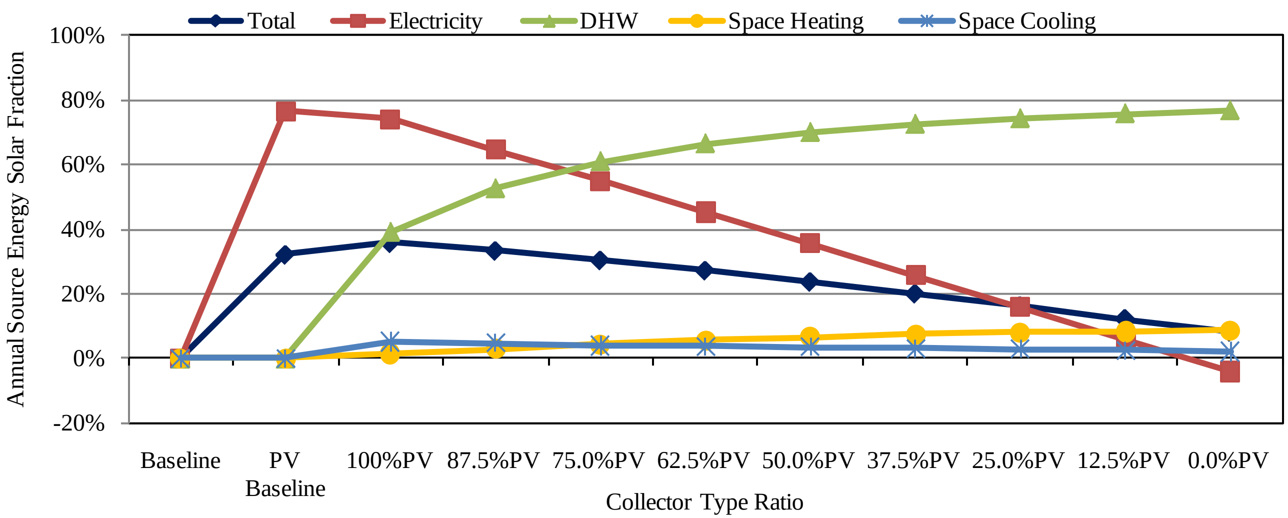


Albuquerque

Simulation Results
Air PV/T with Thermal Boost

- Evaluate alternative collector configurations
- Increasing glazed thermal boost area yields higher thermal energy and lower electricity production

Simulation	PV Modules	Glazed Modules	Array Width (m)	PV Length (m)	Glazed Length (m)
PV Baseline	32	0	5.7	5.20	0.00
100% PV	32	0	5.7	5.20	0.00
87.5% PV	28	4	5.7	4.55	0.65
75.0% PV	24	8	5.7	3.90	1.30
62.5% PV	20	12	5.7	3.25	1.95
50.0% PV	16	16	5.7	2.60	2.60
37.5% PV	12	20	5.7	1.95	3.25
25.0% PV	8	24	5.7	1.30	3.90
12.5% PV	4	28	5.7	0.54	4.55
0.00% PV	0	32	5.7	0.00	5.20



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Simulation Results
Air PV/T with Thermal Boost

- Increased glazing area gives higher collector efficiency, but lower system efficiency
- Net thermal efficiency near 5%

Simulation	PV Modules	Glazed Modules	Array Width (m)	PV Length (m)	Glazed Length (m)
PV Baseline	32	0	5.7	5.20	0.00
100% PV	32	0	5.7	5.20	0.00
87.5% PV	28	4	5.7	4.55	0.65
75.0% PV	24	8	5.7	3.90	1.30
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37.5% PV	12	20	5.7	1.95	3.25
25.0% PV	8	24	5.7	1.30	3.90
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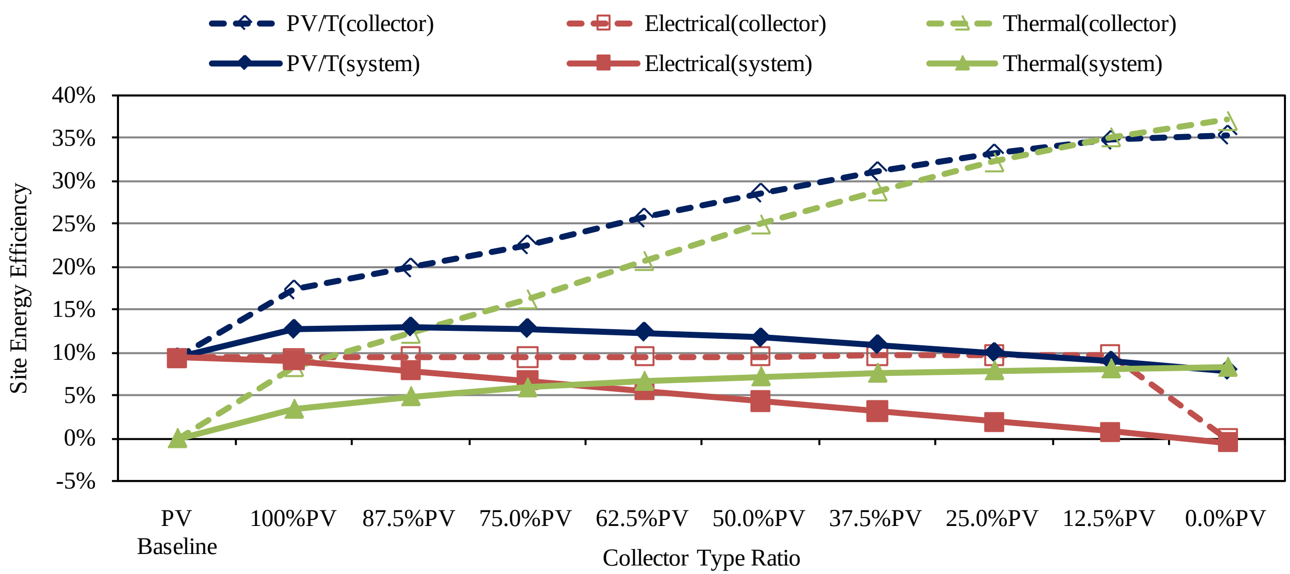
0.00% PV	0	32	5.7	0.00	5.20



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Simulation Results
Air PV/T with Thermal Boost

- Evaluate alternative collector configurations
- Minimum source energy with no glazed thermal boost

Simulation	PV Modules	Glazed Modules	Array Width (m)	PV Length (m)	Glazed Length (m)
PV Baseline	32	0	5.7	5.20	0.00
100% PV	32	0	5.7	5.20	0.00
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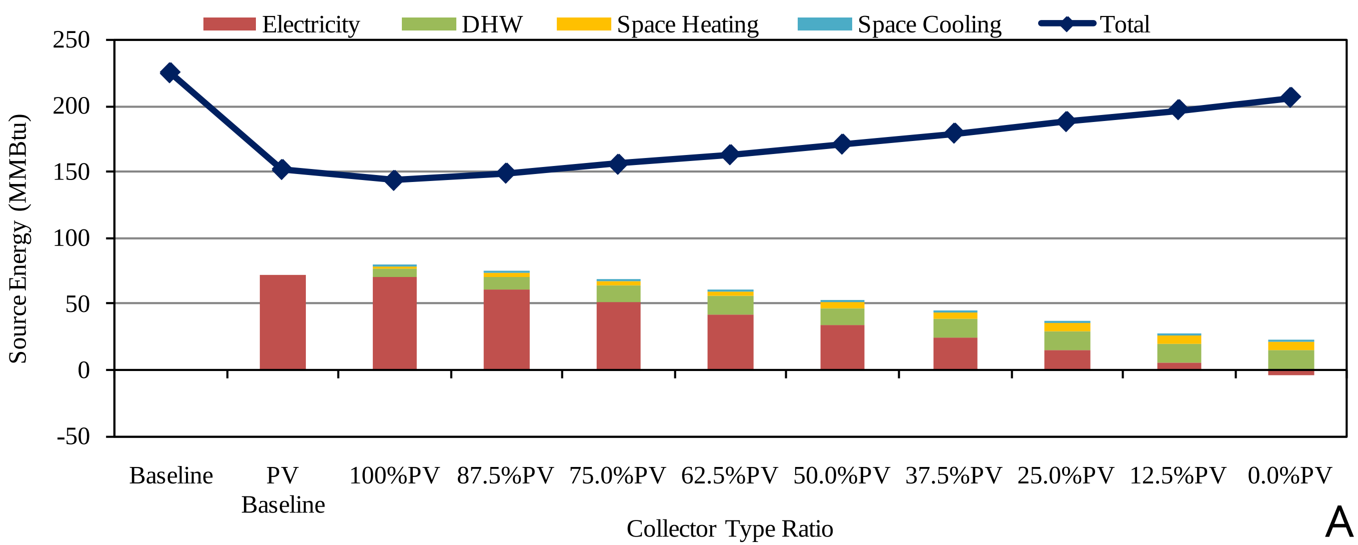


Albuquerque

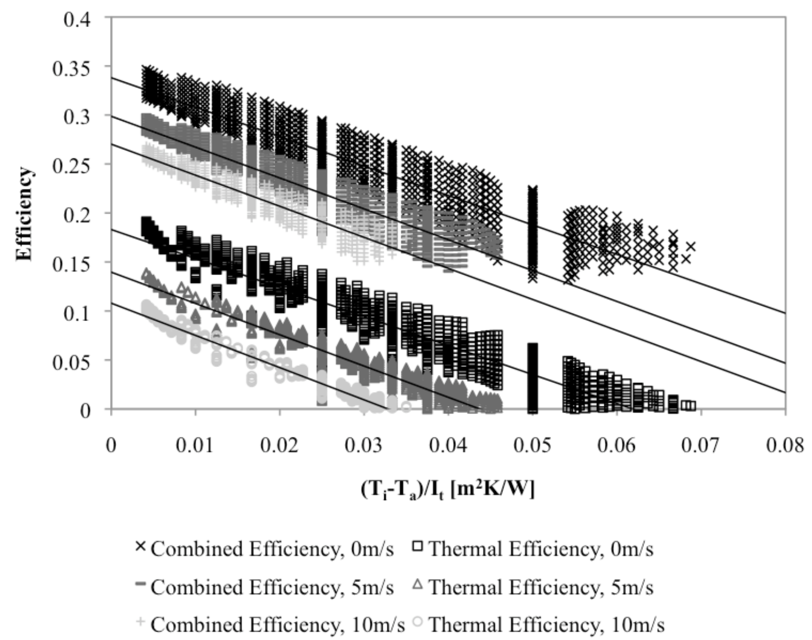
Simulation Results
Air PV/T with Thermal Boost

- Seven climates
- Energy costs based on 2008 state averages
- Area constrained to size of 4 kW PV system
- Minimum source energy achieved with all PV/T – no thermal boost

City	Maximum Site Ratio	Annual Useful Site Energy (MMBtu)	Maximum Source Ratio	Annual Useful Source Energy (MMBtu)	Maximum Cost Ratio	Annual Energy Cost Savings
Albuquerque	87.5%PV	29.77	100%PV	80.36	100%PV	$707
San Francisco	87.5%PV	24.41	100%PV	67.81	100%PV	$839
Chicago	87.5%PV	20.64	100%PV	57.68	100%PV	$548
Fargo	87.5%PV	21.30	100%PV	60.26	100%PV	$399
Atlanta	100%PV	22.91	100%PV	64.67	100%PV	$603
Tampa	100%PV	22.63	100%PV	76.13	100%PV	$754
Phoenix	100%PV	27.08	100%PV	91.13	100%PV	$807

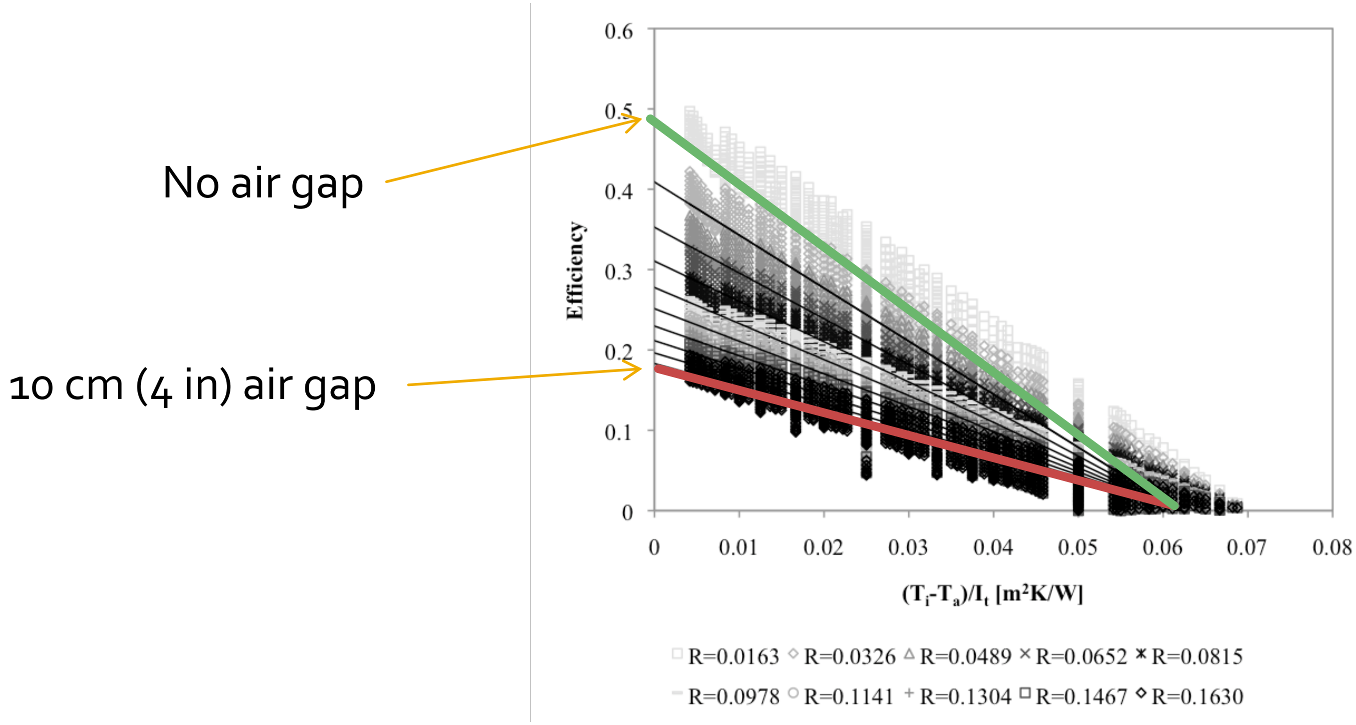
Simulation Results Liquid PV/T Retrofit

- Parametric analysis of liquid collector with air gap between PV and fluid channels
- Collector thermal efficiency depends on wind speed
- Combined efficiency boosted by thermal performance



Simulation Results
Liquid PV/T Retrofit

- Eliminating air gap increases efficiency by 2.5x
- Gap doesn't affect minimum radiation level to produce heat



Conclusions
Observations

- DHW offers greater opportunities than space heating or night cooling
- PV/T gives relatively low thermal efficiency, but large area can result in solar fractions equivalent to traditional flat-plate collector
- Air system allows simple collector, but require fan and coil to deliver DHW
- Liquid system cannot be simply bonded to PV without compromising UL certification
- Increase in electrical efficiency modest (<5% at high insolation)

Conclusions
Gaps and Barriers

- Air PV/T
  - Simple collector, but complicated system
  - Additional fan and ducting costs compared to conventional SDHW system
  - Lower efficiency due to air-to-liquid heat exchanger
- Liquid PV/T
  - Simple system, but complicated or very low-efficiency collector
  - High thermal performance suggests integrated collector with separate UL certification
  - Requires modularity with quick plumbing connection
  - Freeze protection in cold climates
- Few products, limited experience
- Installation involves multiple trade