ESL-TR-04/07-01

OVERVIEW OF SOLAR ENERGY RESEARCH: 1990 TO PRESENT

Briefing

Prepared for

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British Consulate

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ENERGY SYSTEMS LABORATORY

Texas Engineering Experiment Station
Texas A&M University System

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1 Introduction: Energy Systems Laboratory

The Energy Systems Laboratory (ESL), established in 1939, is a division of the Texas Engineering Experiment Station, and a member of the Texas A&M University System. The ESL has successfully performed over $25 million in research for dozens of government and private sponsors including ASHRAE, USDOE, USEPA, DoD, and the state of Texas, over the last 15 years.

The ESL specializes in field research that includes both metering and monitoring energy use in buildings as well as modeling and analysis of the data collected. The ESL provides services in the area of Metering and Analysis technology, such as those developed for the Texas LoanSTAR Metering and Monitoring Program, including calibrated simulation, and measurement and verification of photovoltaic solar installations. Throughout the past twelve years the ESL has assembled a nationally recognized team of professionals who have raised metering and monitoring in Texas to a point of national prominence.

The ESL has also conducted notable studies in solar radiation, including participation in the Thin-Film Photovoltaics Partnerships Program (TFPPP), development of new multipyranometer arrays, solar radiation design tools for architects, shaded fenestration studies, analysis of triple-effect solar panels, building integrated photovoltaic studies, and studies of .

The ESL has some of the best technical and analytical capability in building energy monitoring and analysis in the United States, including the Texas LoanSTAR program which is clearly one of the leading conservation retrofit programs in the United States. The ESL also maintains a NIST-traceable calibration laboratory to calibrate sensors and monitoring systems, including electrical metering, and we have established a web-based, statewide data retrieval network in Texas, which can collect and process over two megabytes of data daily from remote loggers.

The ESL has been involved in designing and installing monitoring systems and analyzing and reporting the results for multi-year periods. We have designed and installed monitoring systems at over 140 sites, collecting over 3,300 channels of data from more than 400 buildings. We have developed and implemented procedures for analyzing and reporting data on measured savings, which set the standard for the field.

Figure 1: View of the Energy Systems Laboratory Offices in the Wisenbaker building on the Texas A&M Campus.

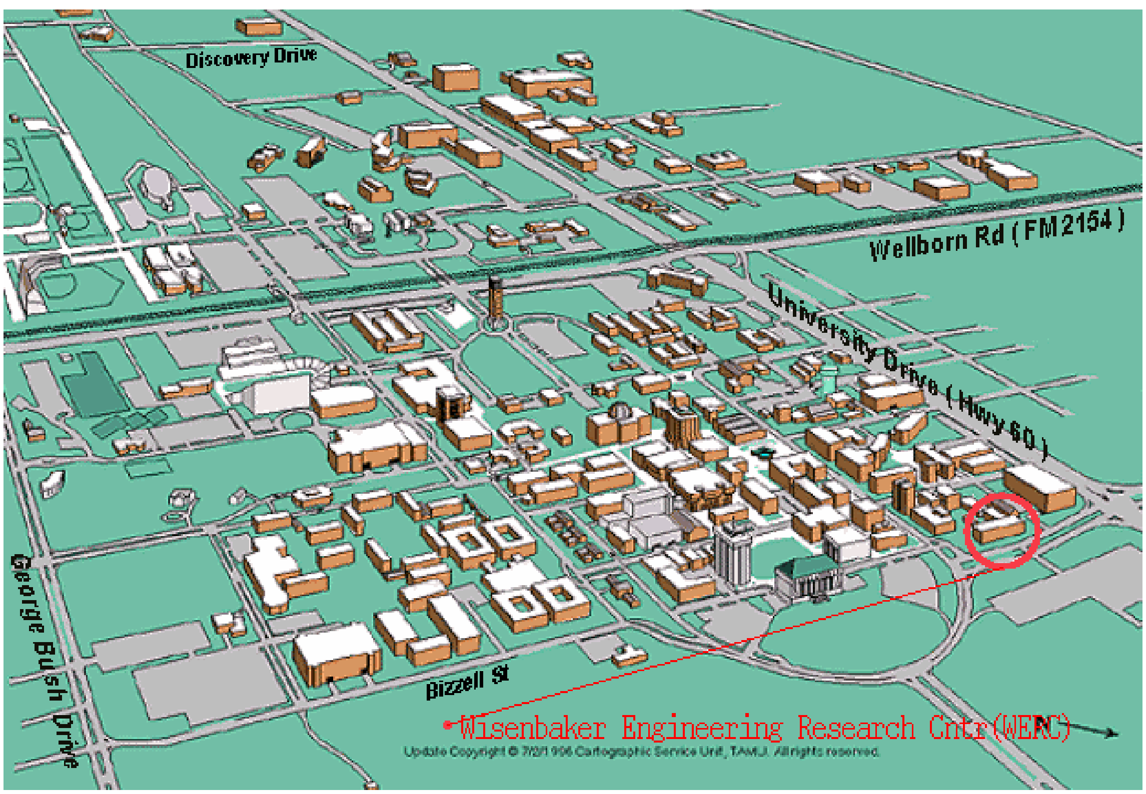

Figure 2: Location of the Wisenbaker building on the Texas A&M University Campus.

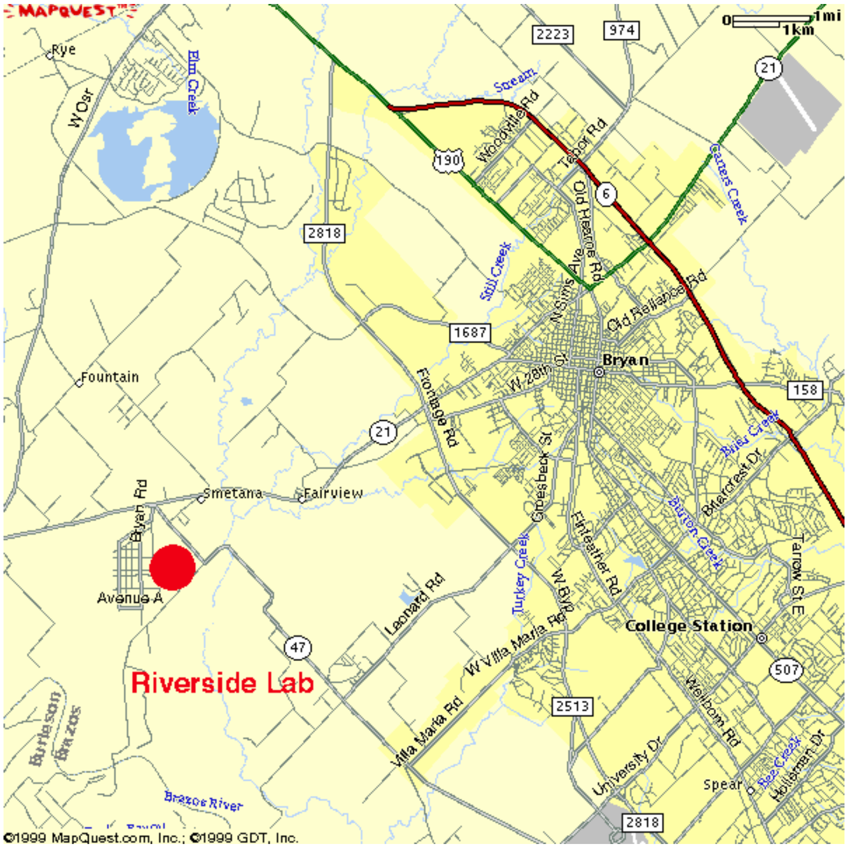

Figure 3: Location of the Energy Systems Laboratory Riverside Lab

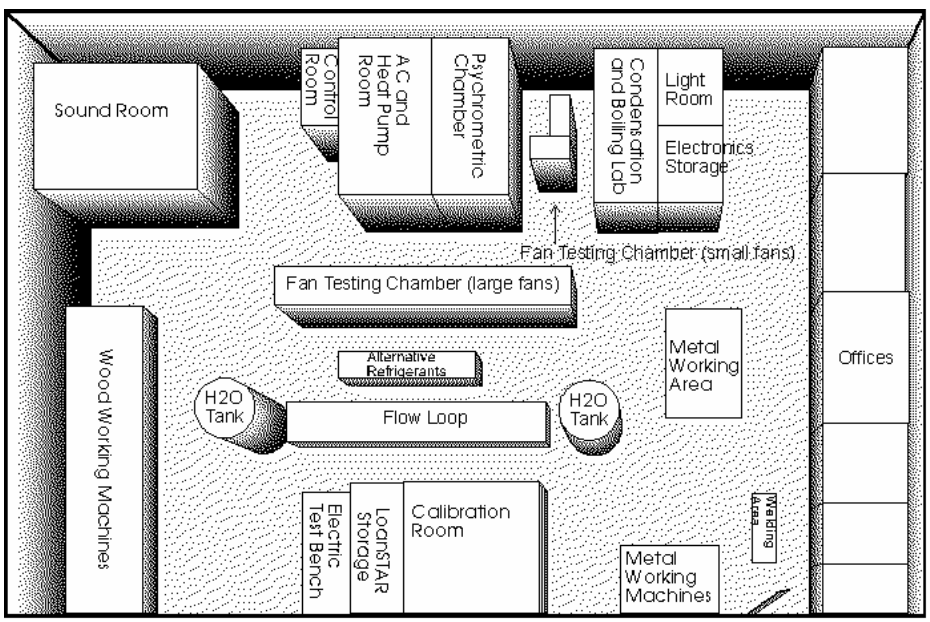

Figure 4: Layout of the ESL's Riverside Laboratory.

Figure 5: Photo of the ESL's Air Flow Chamber. This chamber is capable of measuring air flow as high as 50,000 CFM with accuracy of + - 1% , and can test fans with diameters of 8 ft, using ANSI/AMCA Standard 210-85.

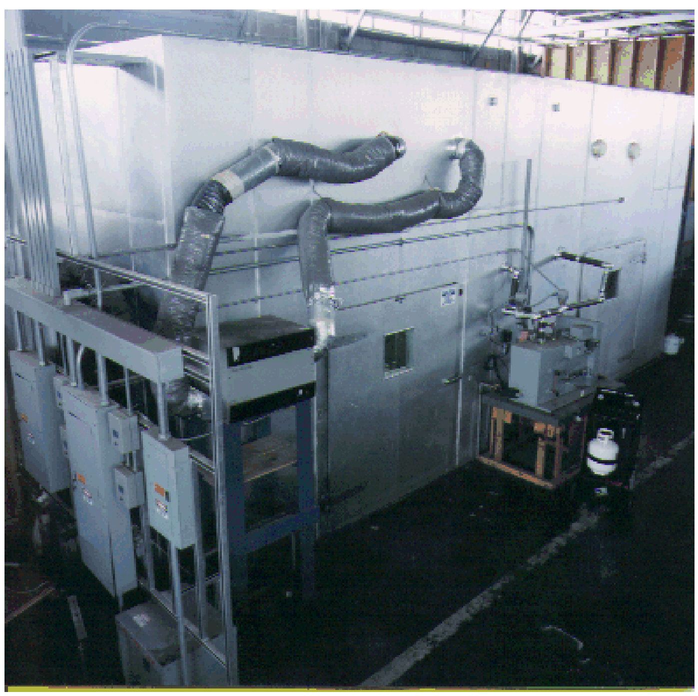

Figure 6: Photo of the ESL's Psychrometric Test Facility. This facility provides a controlled environment for testing unitary air conditioning and heat pump systems, +10~F to +120~F, and to measure relative humidity from 5% to 95%, with air flow rates from 150 CFM to more than 5,000 CFM in an AMCA flow chamber (ASHRAE Standards 116-83 and ARI 210/240-89).

Figure 7: Photo of the ESL's Dynamic Weight Liquid Flow Loop. This flow loop measures flow rates using dynamic weight, as well as 2nd and 3rd reference standards (i.e., orifice plate, and magnetic meter). The flow loop is used to develop dynamic flow accuracies for flow meters in 3 to 12 inch diameter pipes, with flow rates varying from 50 to 650 gpm.

The ESL testing and research procedures include:

- Air Flow Test Standard Verification Procedure
- Sound Test Standard
- Air Movement and Control Association (AMCA) Standards
    - 210-85, Laboratory Methods for Testing Fans for Ratings
    - 301, Methods of Calculating Fan Sound Rating from Laboratory Test Data
    - 500, Test Methods of Louvers, Dampers and Shutters
- American Society of Mechanical Engineers (ASME) Standard
    - ASME-MFC-3M-1985, Measurement of Fluid Flow in Pipes Using Orifice, Nozzle and Venturi
- American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) Standards
    - 25-90, Method of Testing: Forced Convection and Natural Convection Air Coolers for Refrigeration
    - 33-78, Method of Testing: Forced Circulation Air Cooling and Air Heating Coils
    - 41.1-86, Standard Measurement Guide: Section on Temperature Measurements
    - 41.6-82, Standard Method for Measurement of Moist Air Properties
    - 51-85, Laboratory Methods of Testing Fans for Ratings
    - 116-83, Method of Testing: Seasonal Efficiency of Unitary Air Conditioners and Heat Pumps

Air Conditioning and Refrigeration Institute (ARI) Standards

- 210-1989, Standard for Unitary Air Conditioning Equipment
- 240-1989, Standard for Air-Source Unitary Heat Pump Equipment

2 U.S.D.O.E. Thin Film Solar Test Bench (Riverside)

Background.

Thin-Film Photovoltaics Partnerships Program (TFPPP) is meant to accelerate the progress of thin film solar cells and module development as well as to address mid- and long-term research and development issues. The long-term objective of the TFPPP is to demonstrate commercial, low-cost, reproducible, high yield and robust modules of 15% efficiency. Furthermore, this research is directed at making progress toward this objective by achieving interim goals in thin film module efficiencies; cell and module processing; cell and module reliability; and the necessary fundamental research needed to build the technology base that support these key areas.

The DOE/NREL/NCPV strategy in undertaking this R&D effort is to maintain the good coupling between laboratory results from fundamental materials and processes research to manufacturing R&D, pilot-line operation, and early entry of advanced thin-film PV products to the ever-growing marketplace worldwide. The thin-film module reliability project therefore has engaged Texas A&M to deploy modules outdoors in specified high humidity/temperature with a goal to identify changes and failure in the modules. The purpose of this undertaking is to develop accelerated stress test to duplicate such mechanisms occurring in the field after longer times, and ultimately determining the mechanisms leading to performance changes and/or failure.

The purpose of the ESL’s work for the USDOE is to:

(1) test sets of cadmium telluride (CdTe), copper indium diselenide (CIS), and amorphous silicon (a-Si) modules outdoors and outdoors under high voltage conditions,

(2) maintain these tests for the time needed to diagnose problems, and

(3) set up a testing capability that can respond to further requests for similar tests. For this purpose, the offeror will install, monitor, and evaluate up to 182 photovoltaic (PV) thin-film modules manufactured by five companies:

- Shell Solar (Glass/CIS/Glass),
- Global Solar (CIS flexible Fiber glass substrate),
- First Solar (Glass/CdTe/Glass),
- United Solar (a-Si on flexible substrate) and
- Energy Photovoltaics (Glass/ a-Si /Glass)

Modules will be installed on ESL's Riverside Lab testing facility. The ESL will share the information found about the modules as specified and will actively participate in the National R&D Team activities. The ESL's sensors at the test bench include:

WEATHER SENSOR	NUMBER OF SENSORS
Temperature	3
RH	3
Eppley PSP	3
Eppley UV	3
Diffuse PSP	2
Lightning	1
Ultrasonic Wind Speed	1
Wind Speed & Dir	1
Hail Sensor	1

Figure 8: Photo of the ESL's Thin Film Solar Test Bench under construction (view from south).

Figure 9: Photo of the ESL's Thin Film Solar Test Bench under construction (left: close-up of panels being loaded onto test bench, right: computer cluster for archiving and storing web-based data acquisition).

3 Statewide Emissions Reductions From the use of Renewable Energy Systems

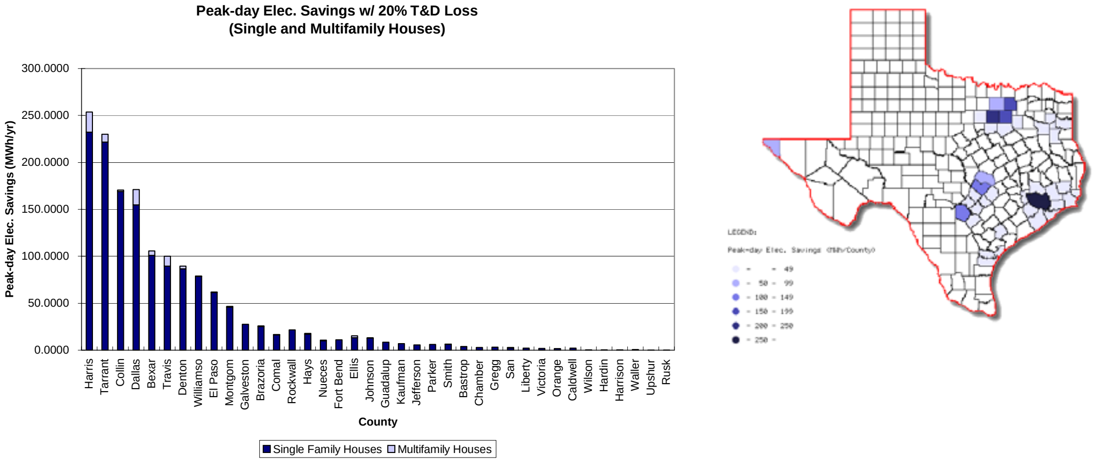

Figure 10: 2003 Peak-day electricity reductions from 2000 IECC by PCA for single-family and multi-family residences by county using eGRID.

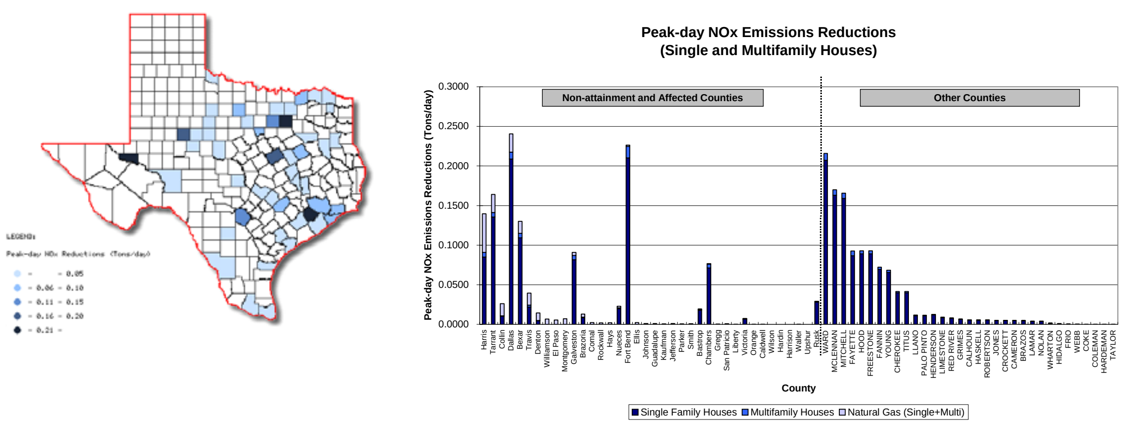

Figure 11: 2003 peak day NOx reductions from electricity and natural gas savings due to the 2000 IECC for single-family and multi-family residences by county

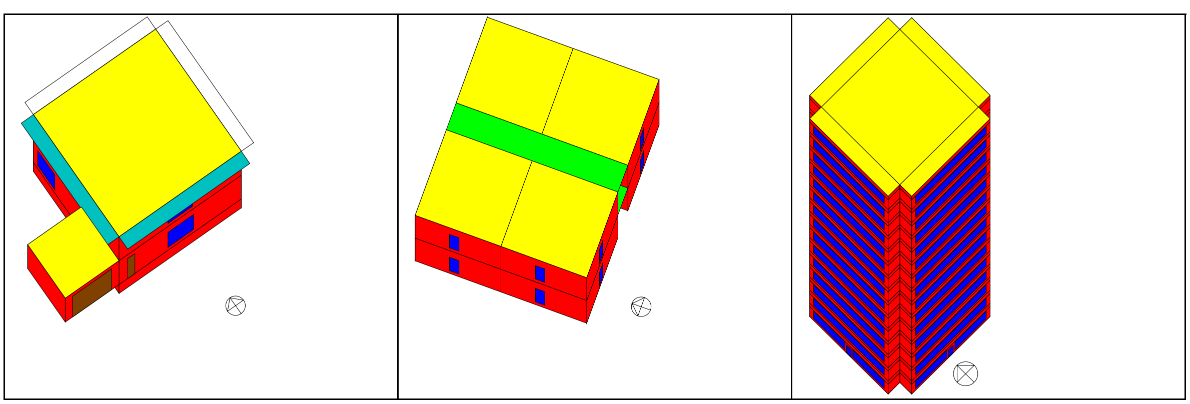

Figure 12: Enhanced calculations to include single-family, multi-family & commercial buildings.

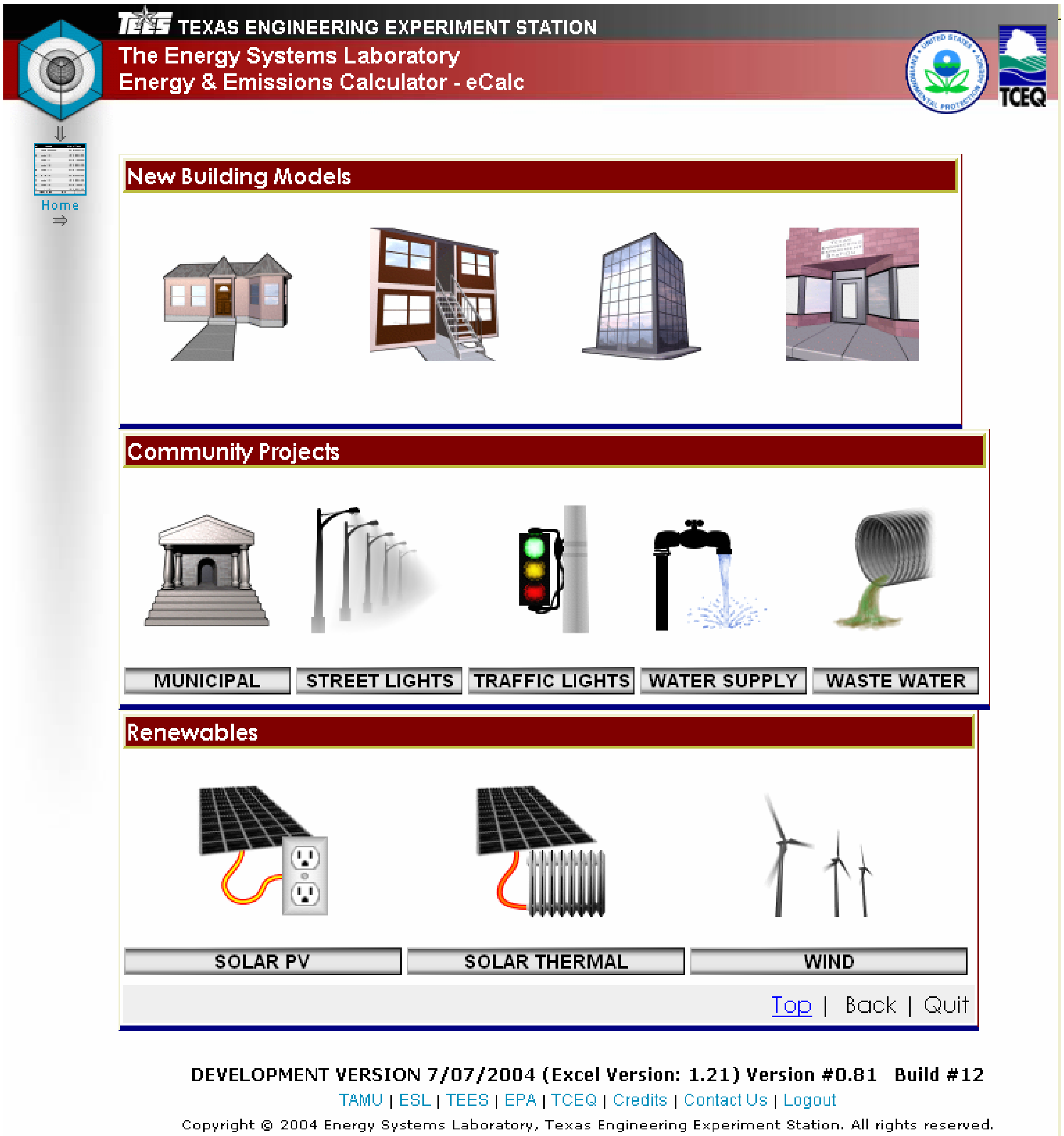

Figure 13: *Screen-image from web-based emissions-reduction calculator (eCALC).*

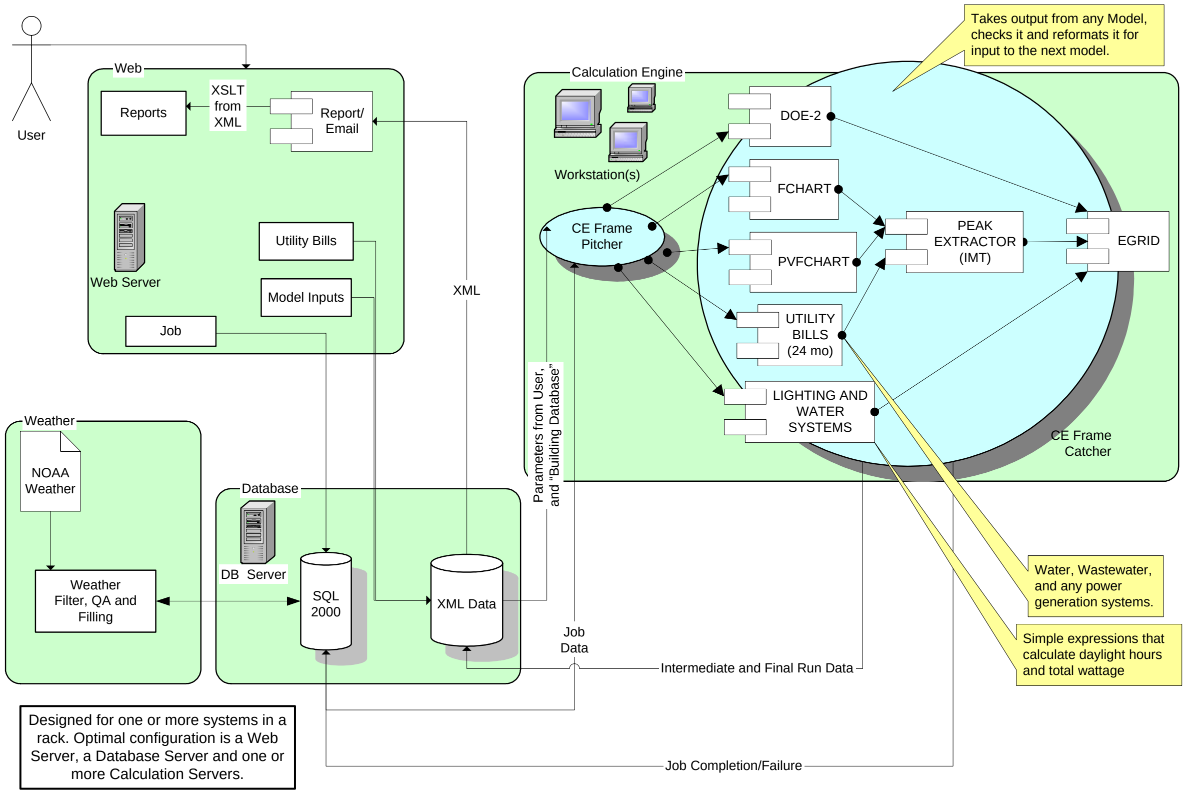

Figure 14 Block-diagram showing interactive-functionality of the emissions reduction calculator.

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Haberl, J., Culp, C., B.Yazdani, T.Fitzpatrick, D.Turner. 2002. "An Introduction to Texas Senate Bill 5", Proceedings of the Thirteenth Symposium on Improving Building Systems in Hot and Humid Climates, Texas A&M University, Houston, Texas, pp. 1-10, (May).

Haberl, J., Culp, C., Gilman, D., Yazdani, B., Fitzpatrick, T., Munns, S. 2004. "Calculation of NOx Emissions Reductions From Energy Efficient Residential Building Construction in Texas", Proceedings of the 2004 International Conference for Enhanced Building Operation, Paris, France (Submitted for publication).

4 Experimental Work and Modeling of Building Integrated PV

Figure 15: Simulated view in a typical office building with and without PV cladding.

Figure 16: Animated sequence for Houston, June 21st, 100% transmittance.

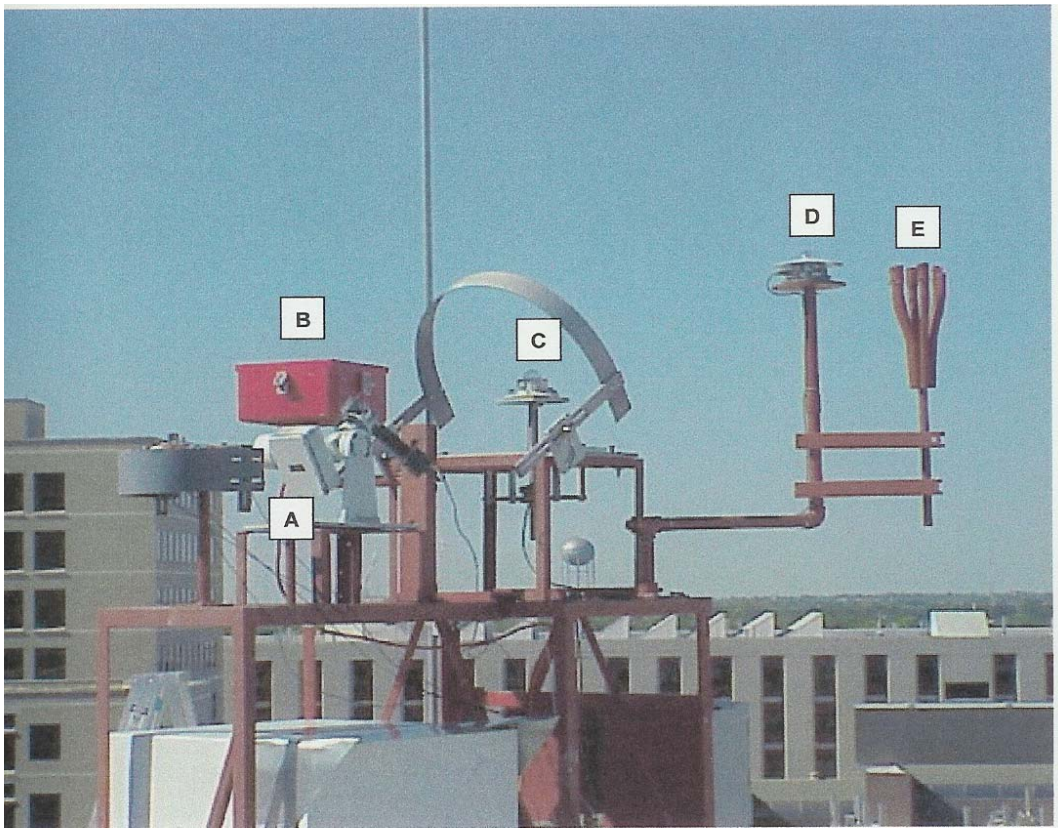

Figure 17: Solar test bench including: a) Eppley NIP, b) transmittance test box, c) shadow-band pyranometer with Eppley B&W, d) Eppley PSP, e) Licor test stand.

Figure 18: Close-up photo of transmittance test box.

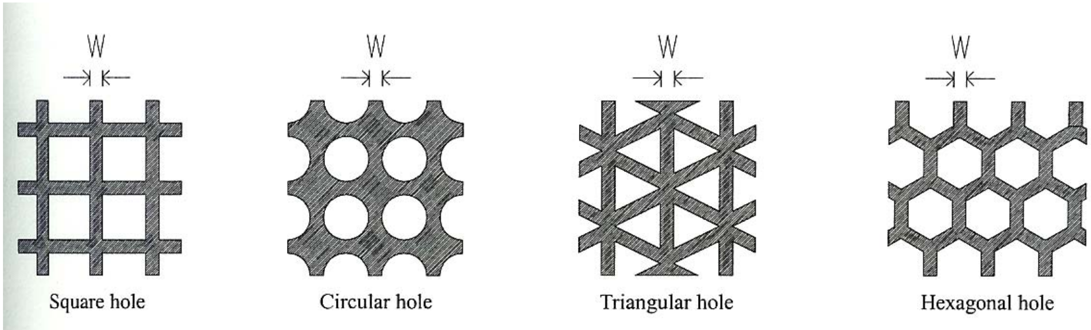

Figure 19: Sample screens used to simulate BIPV on transmittance test box.

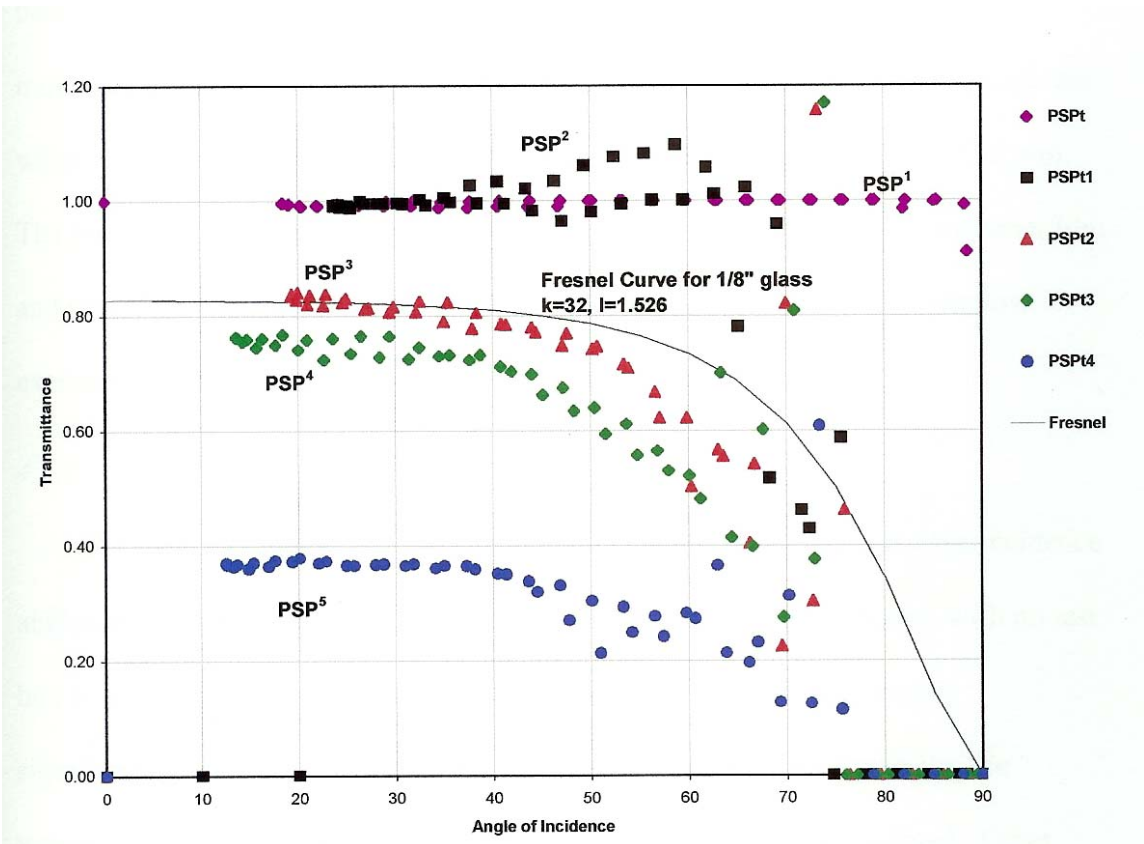

Figure 20: Measured test results for transmittance of BIPV, 1) no box, 2) box only, no glass, 3) glass and frame, 4) glass, frame and plastic film, 5) BIPV.

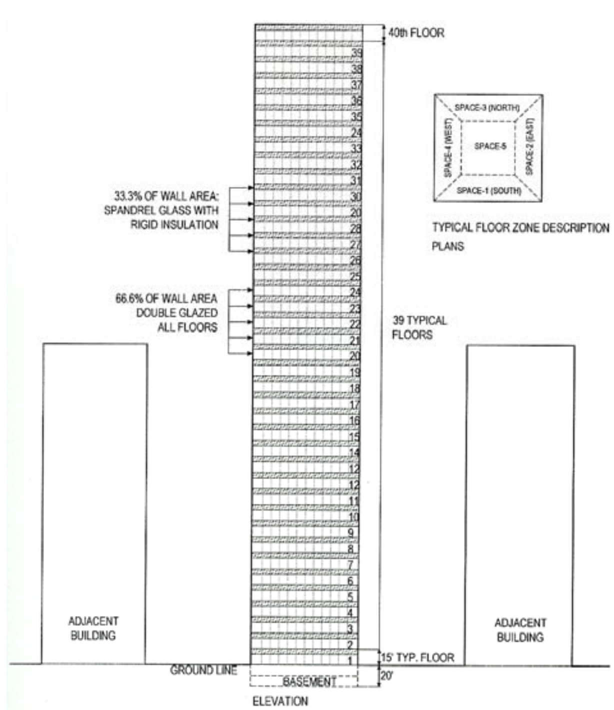

Figure 21: Assumed typical high rise in downtown city block (2D).

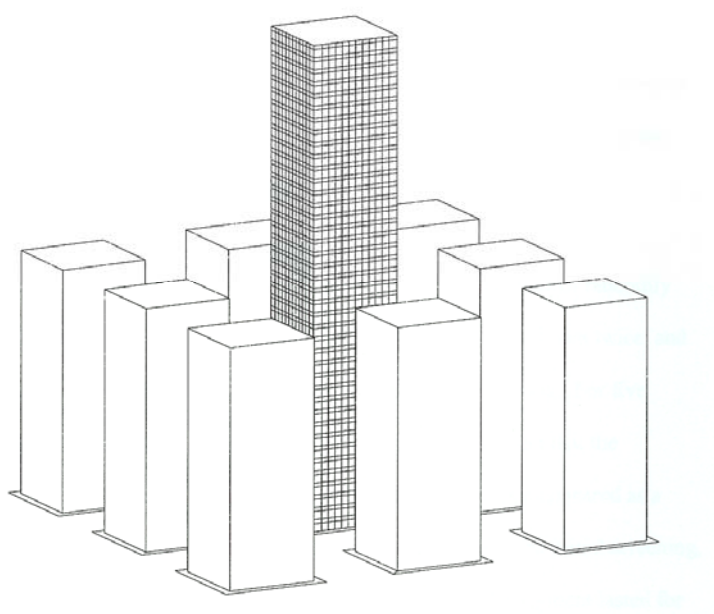

Figure 22: *Assumed typical high rise in downtown city block (3D).*

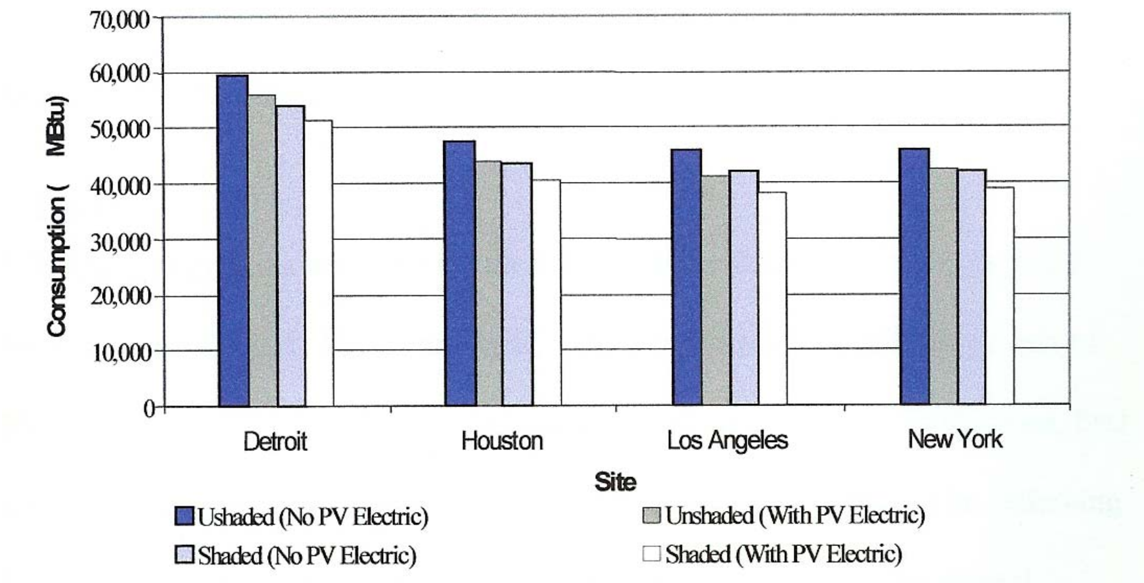

Figure 23: Results of BIPV in four cities.

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5 Performance Assessment of High Efficiency Low-E Windows in State Office Buildings

Figure 24: . Entrance View of the Robert E. Johnson building From the Southwest Corner.

Figure 25: View of windows on south side of building showing light shelf, lighting, and office furniture.

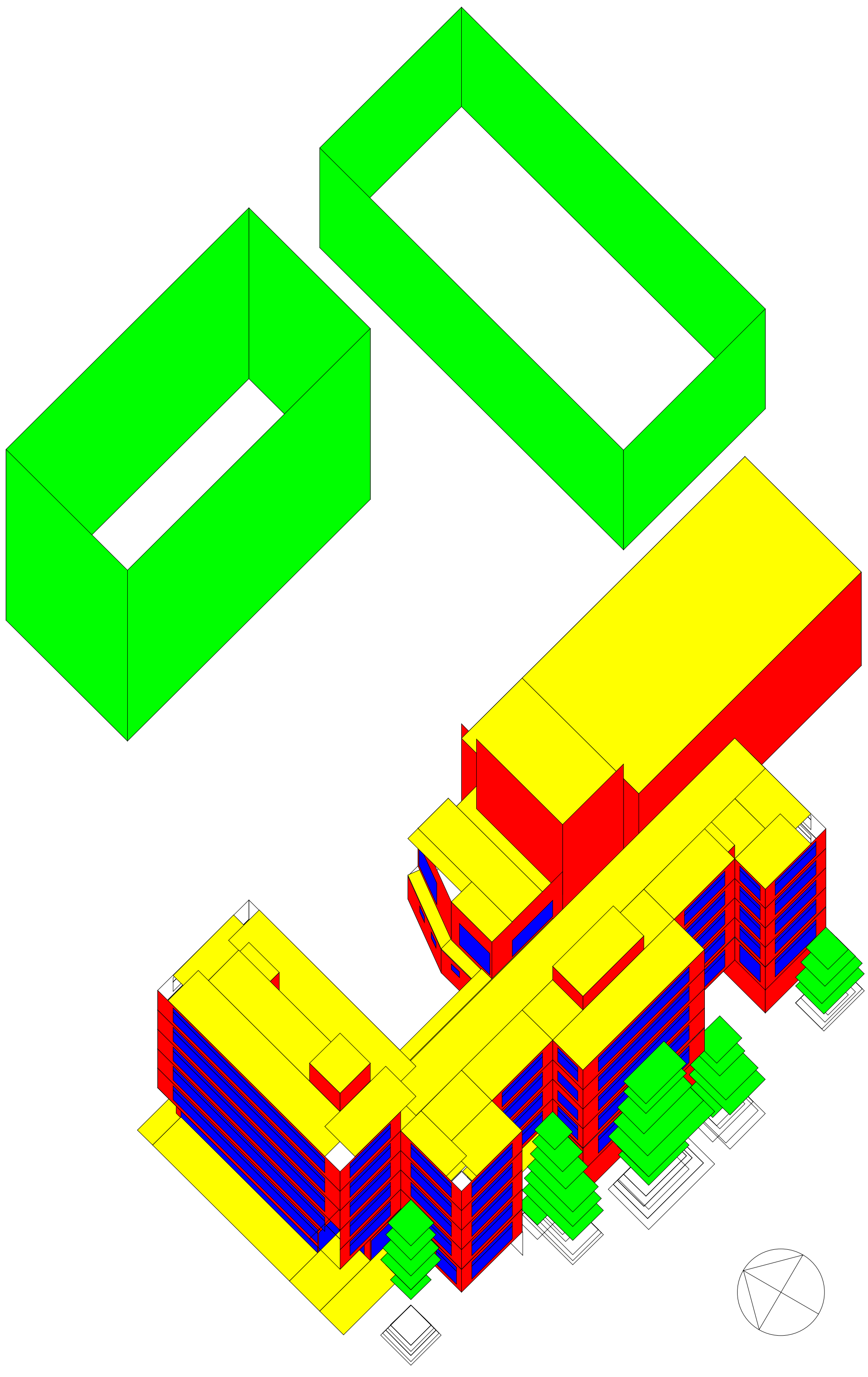


Figure 26: DOE-2 simulation of building showing shading.

NAME	DESCRIPTION	UNIT	EQUATION	CHANNELS
WBE	Whole-building Electricity Use	KWh	The combination of those channels would represent the WBE	Building Electricity 1 Phase A (ch4497)
				Building Electricity 1 Phase B (ch4498)
				Building Electricity 1 Phase C (ch4499)
				Building Electricity 2 Phase A (ch4500)
				Building Electricity 2 Phase B (ch4501)
				Building Electricity 2 Phase A (ch4502)
Chiller #1 Efficiency	Chiller #1 performance (Kw/Ton) at the Certain Capacity (Ton)	kW/Ton	Chiller Elec * 12/ Q(kBtu)	Chiller 1 Electricity Phase A (ch4478)
				Chiller 1 Electricity Phase C (ch4479)
		Ton	Q(KBtu) = (gpm * (supply temp - return temp))/2	Chiller 1 Chilled Water Flow(ch4487)
				Chiller 1 Supply Temperature (ch4485)
				Chiller 1 Return Temperature (ch4486)
Chiller #2 Efficiency	Chiller #2 performance (Kw/Ton) at a certain capacity (Ton)	kW/Ton	Chiller Elec * 12/ Q(kBtu)	Chiller 2 Electricity Phase A (ch4480)
				Chiller 2 Electricity Phase C (ch4481)
		Ton	Q(KBtu) = (gpm * (supply temp - return temp))/2	Chiller 2 Chilled Water Flow(ch4489)
				Chiller 2 Supply Temperature (ch4490)
				Chiller 2 Return Temperature(ch4491)
Building Electric Use	Whole-building Electric Use is break down into end use such as motor control (MCC), Chiller electric use by direct measurement	KWh	WBE	*
			MCC	MCC Electric Phase A (ch4476), MCC Electric Phase C (ch4477)
			Chiller Electricity	(ch4478 + ch4479 + ch4480 + ch4481)
Chiller Temperature	This plot would represent the supply chilled water temperature and return chilled water temperature based on direct measurement	Degree F	Chiller #1 Supply and Return Temp. Chiller #1 Supply and Return Temp.	ch4485, ch4486, ch4490, ch4491
Condenser Temperature	This plot would represent the supply condenser water temperature and return condenser water temperature based on direct measurement	Degree F	Condenser Supply and Return Temp.	ch4495, ch4496
4th Floor Electric use	This plot would represent the 4th floor electric energy consumption, receptacle energy, and lighting energy use	KWh	4th Floor Total Electricity Use	(ch4506+ch4507+ch4508+ch4509+ch4510 +ch4511+ch4512+ch4513+ch4514)
			Receptacle Electricity Use	ch4515+ch4516+ch4517
			Lighting Elec. Use	Total Elec. Use - Receptacle Elec. Use

Figure 27: Monitoring channels for the REJ building.

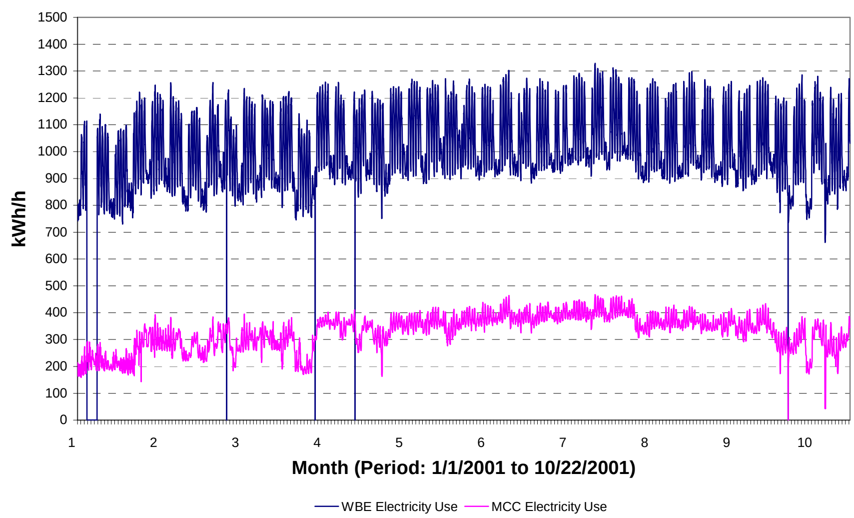
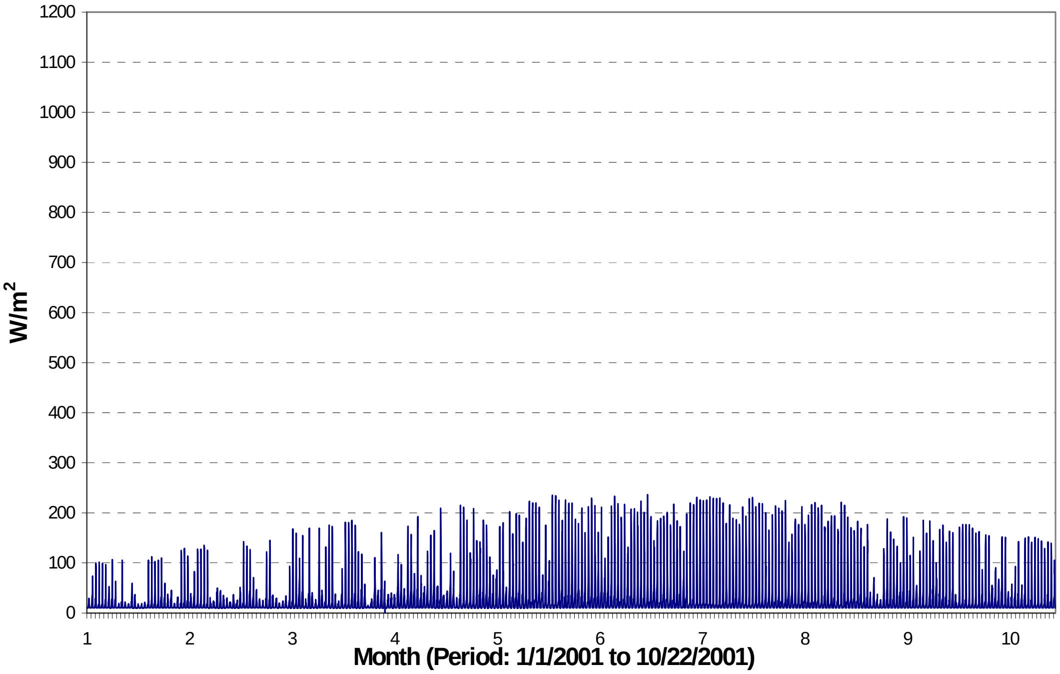


Figure 28: Example measured data from REJ building used for calibrated simulation.



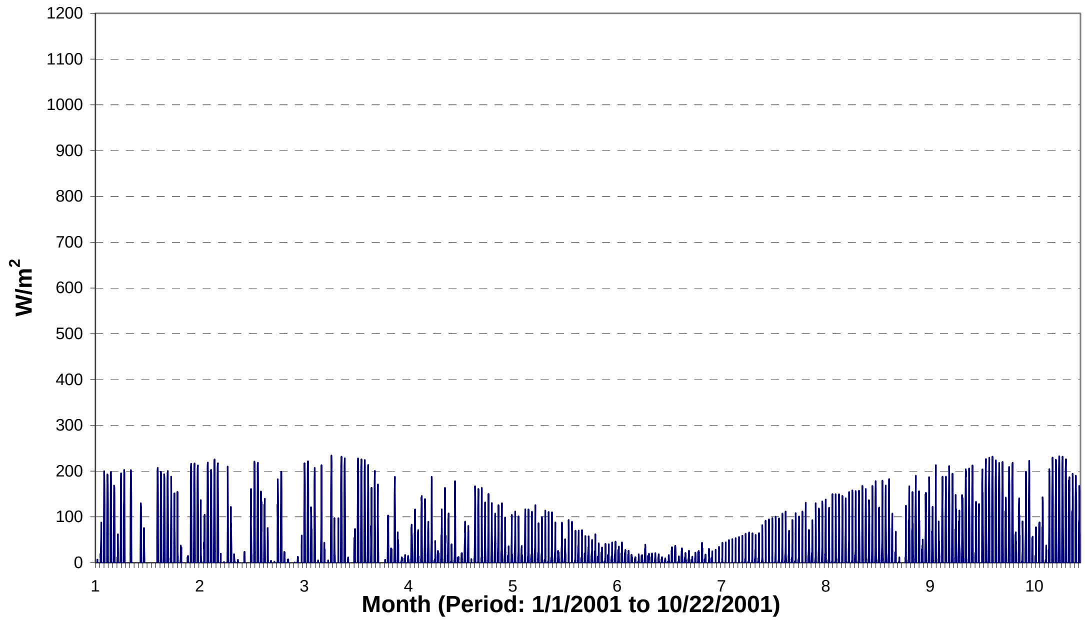


Figure 29: Measured solar radiation data inside of low-e windows for south, and west facing windows.

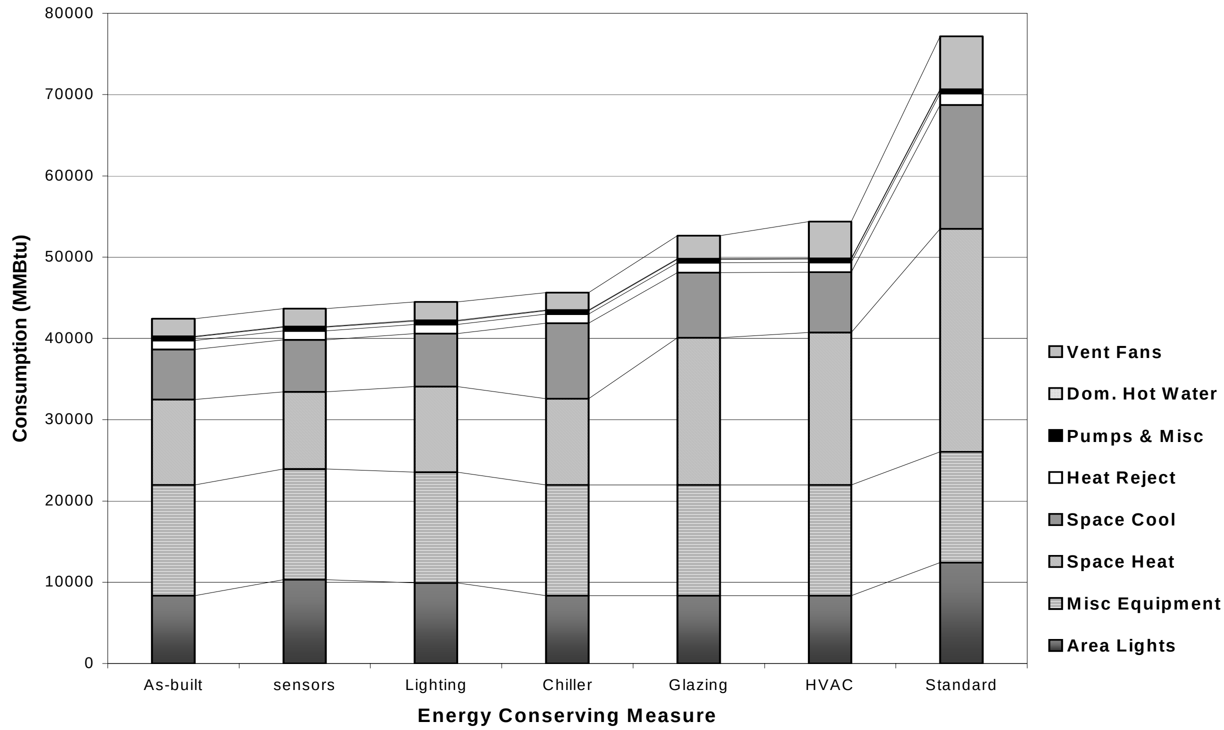


Figure 30: Results of calibrated simulation for REJ building.

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6 Experimental Work on Solar Multipyranometer Array

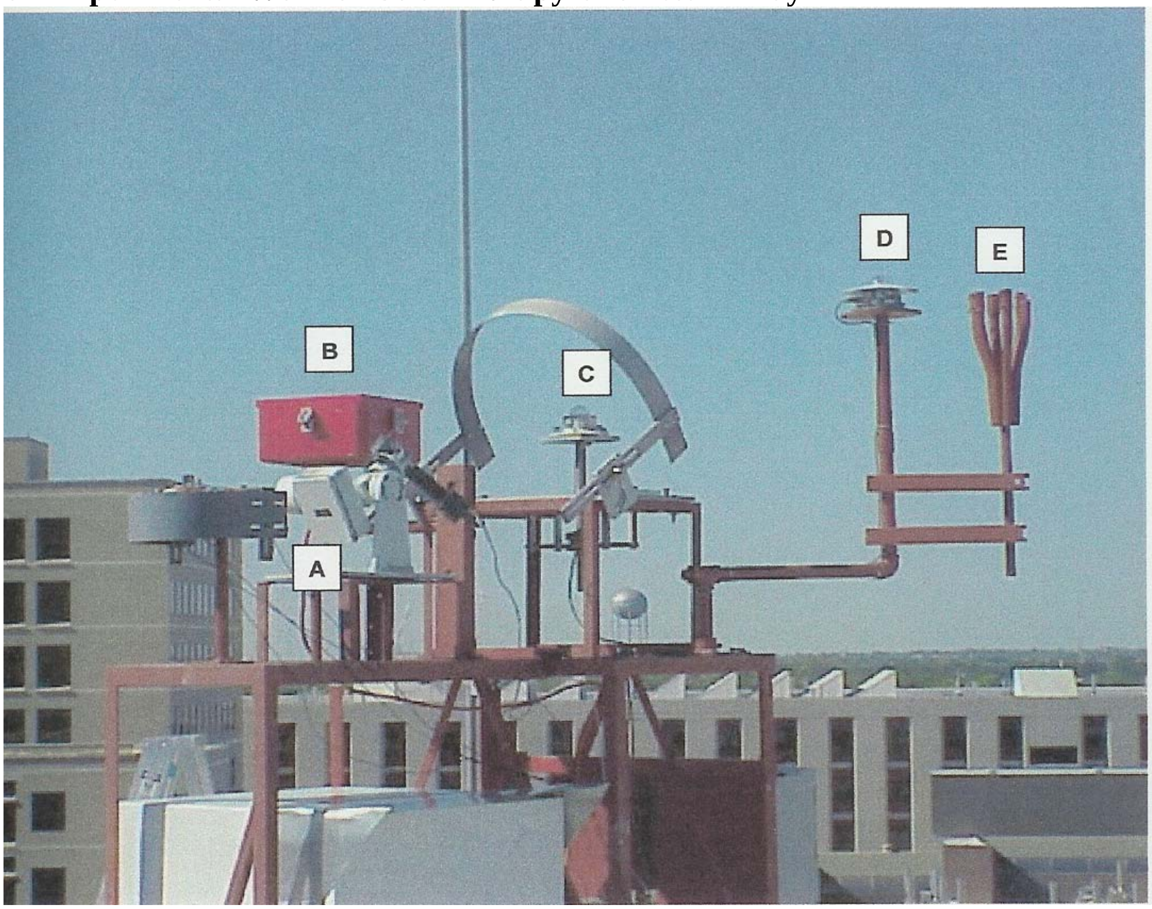

Figure 31: Solar test bench including: a) Eppley NIP, b) transmittance test box, c) shadow-band pyranometer with Eppley B&W, d) Eppley PSP, e) Licor test stand.

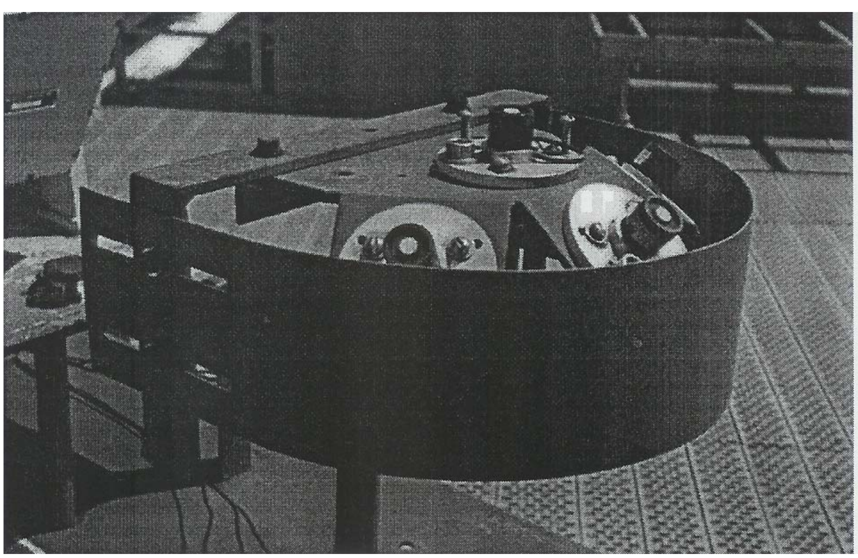

Figure 32: Multipyranometer array.

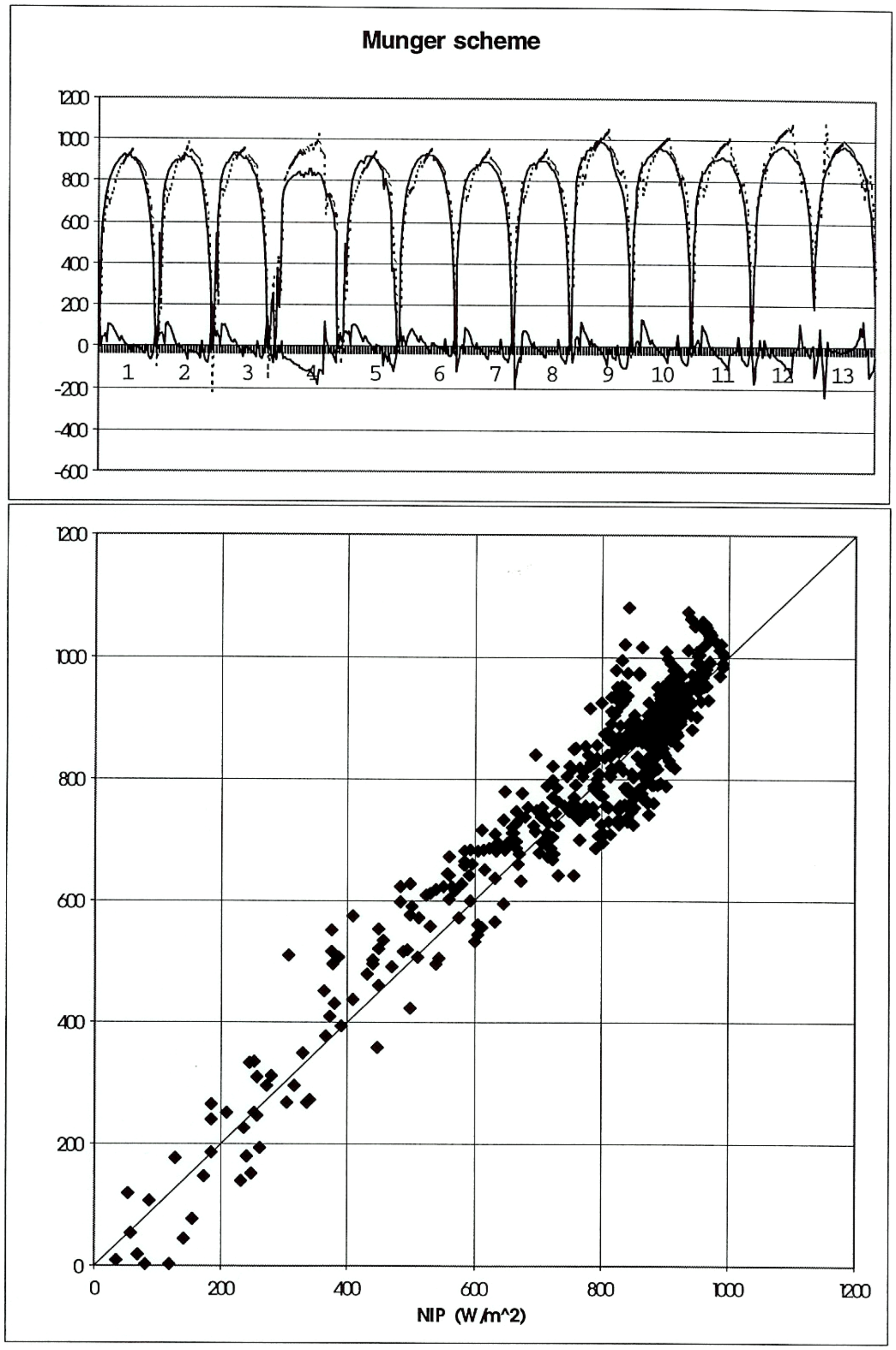

Figure 33: : Example results from early MPA work.

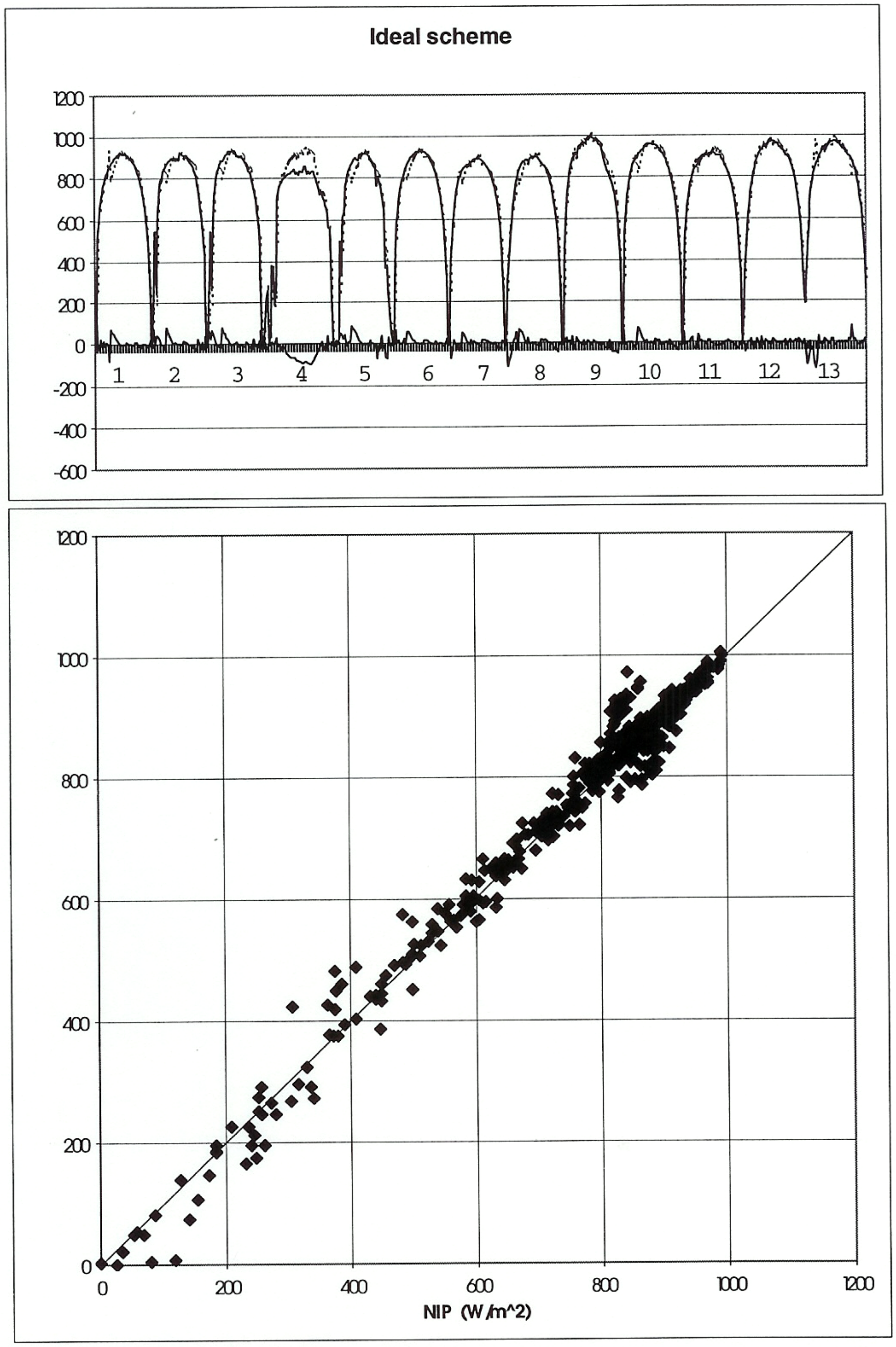

Figure 34: Example results from improved MPA work.

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7 Software Developed for Computerized Sunpath Diagram for Architects

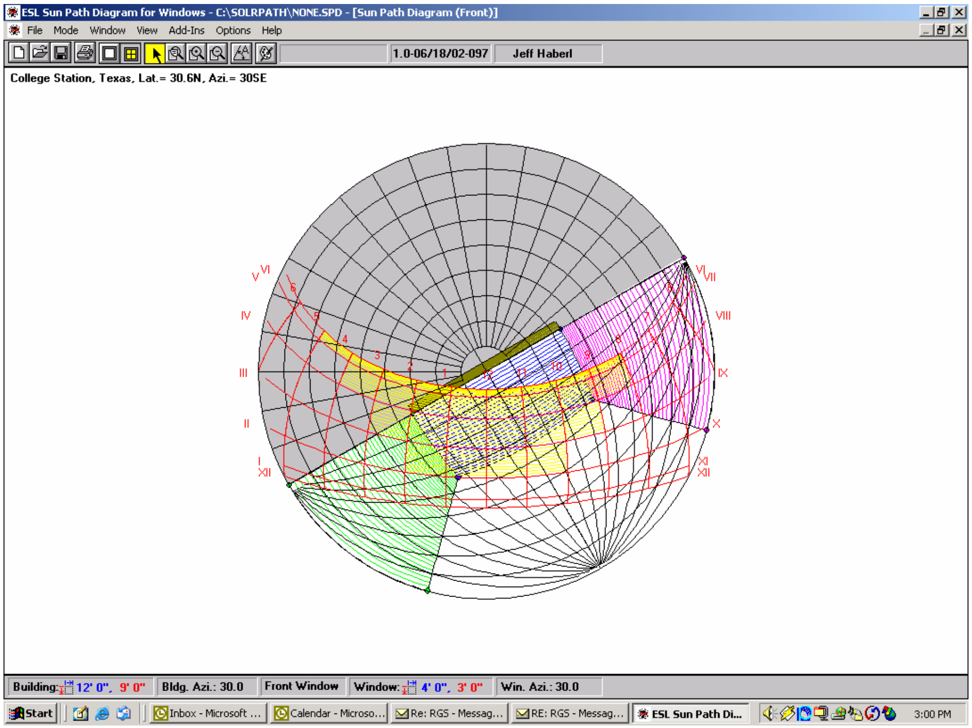

Figure 35: Analysis Screen for the ESL's SOLRPATH solar shading software.

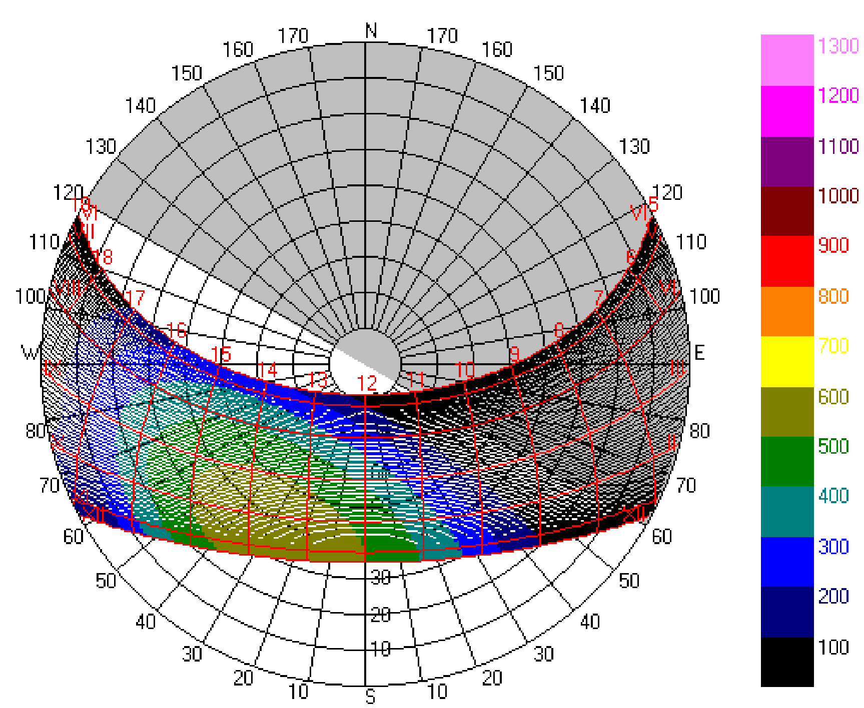

Figure 36: Image of the ESL's advanced solar shading analysis (equidistant projection).

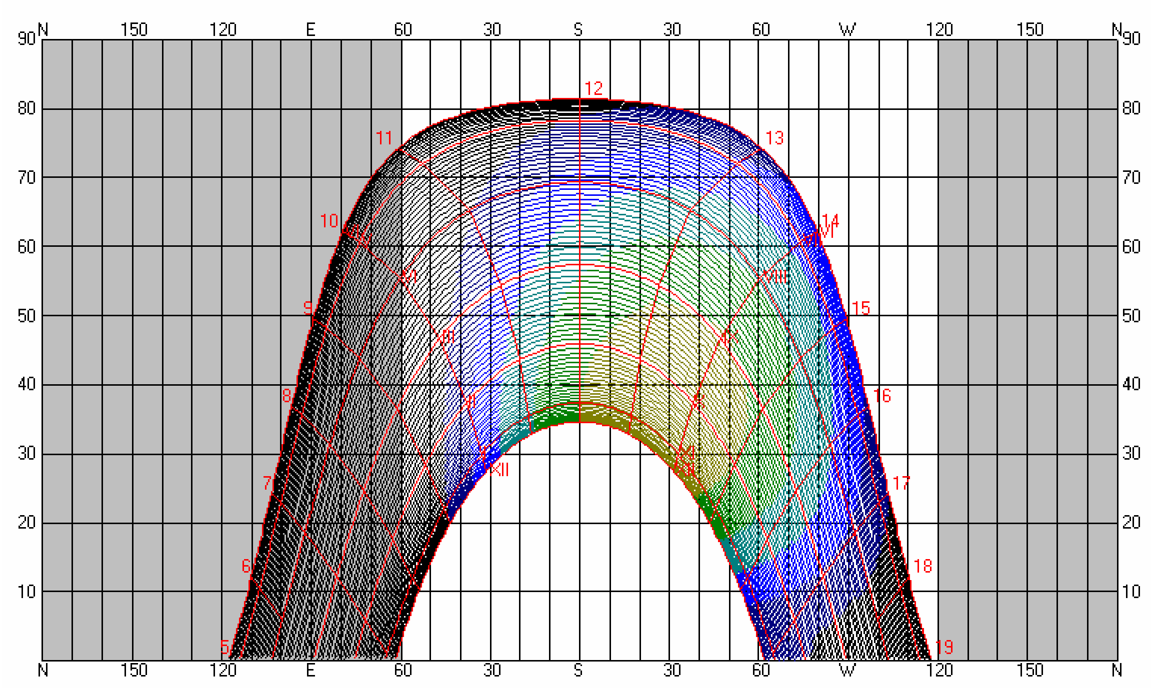

Figure 37: *Image of the ESL's advanced solar shading analysis (cylindrical projection).*

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8 Experimental Work and Modeling of Shaded Fenestration

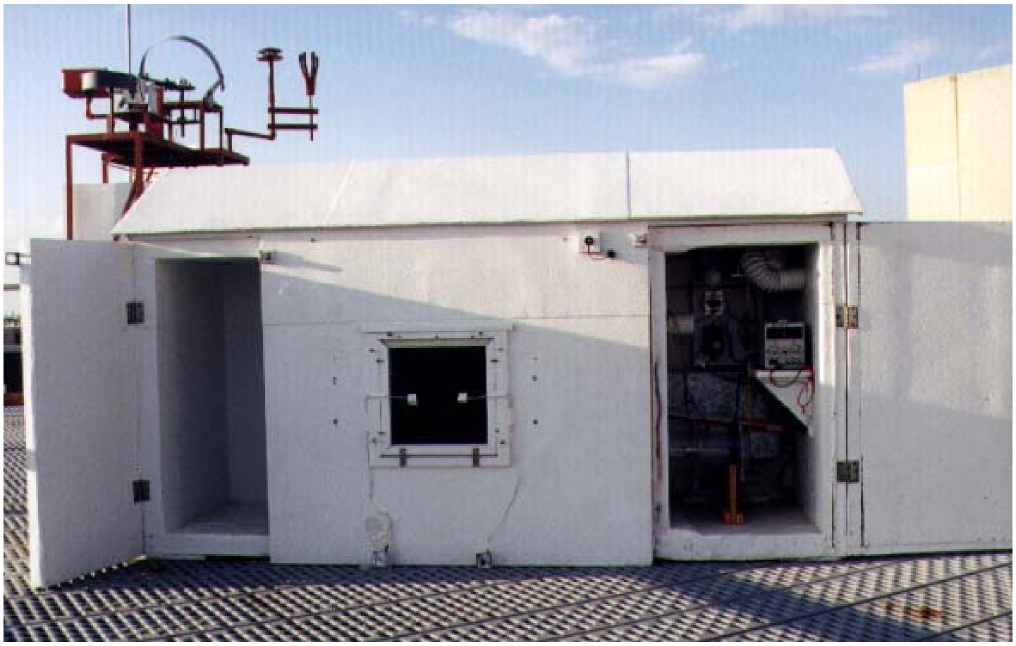

Figure 38: Test facility for shaded fenestration.

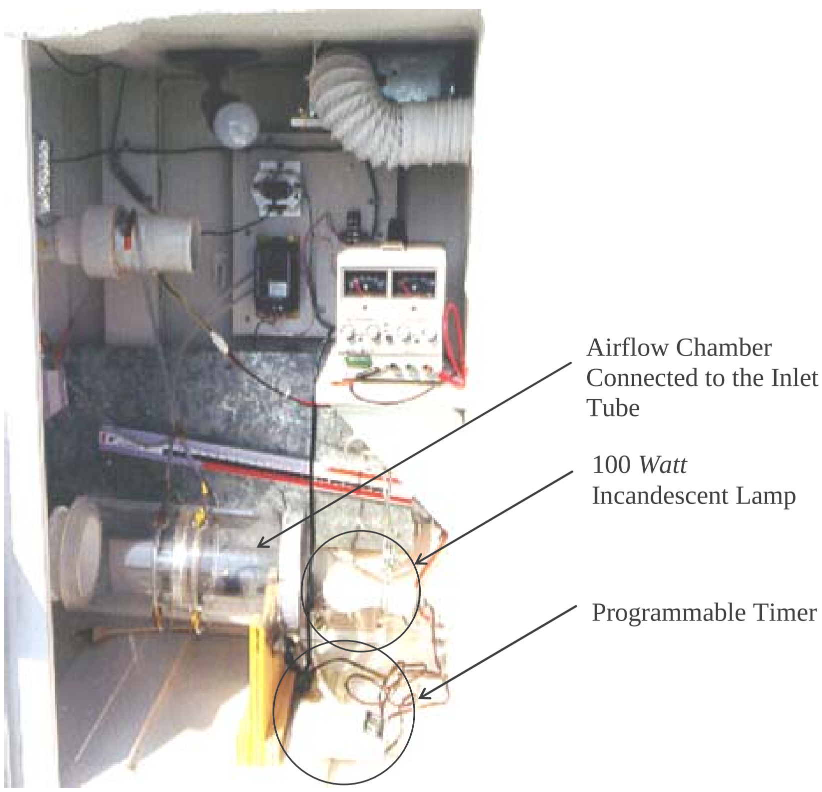

Figure 39: Instrumentation for shaded fenestration test box.

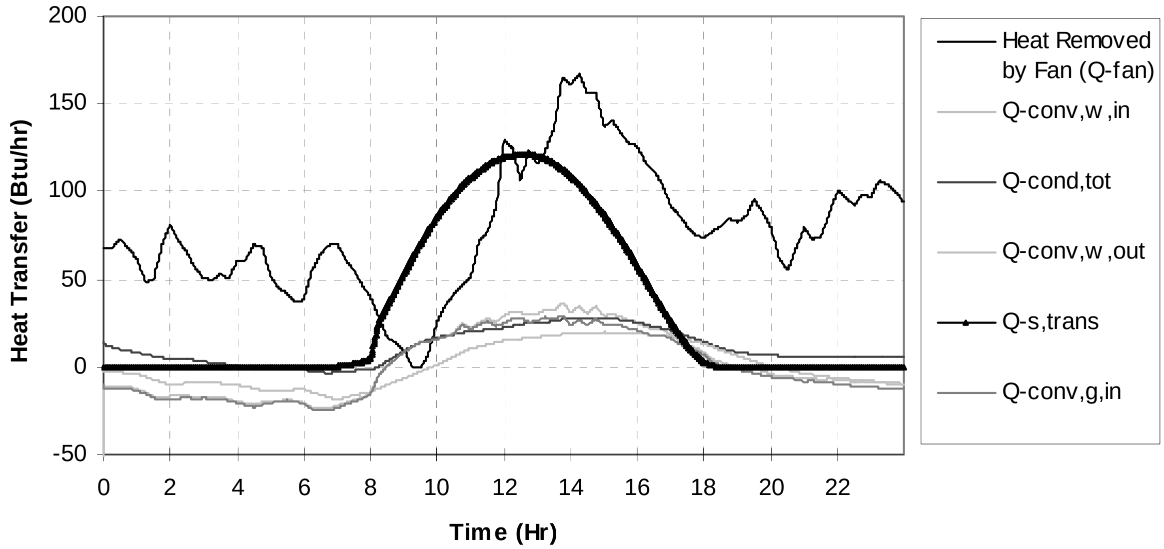

Figure 40: Sample results from shaded fenestration tests.

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Oh., J., Haberl. J. 2001. "Development of a Computer Model for Solar Simulation and Shaded Fenestration Design", ASME Solar Engineering Conference.

Oh, J. 2000. "Development and Validation of a Computer Model for Energy-efficient shaded Fenestration Design", Ph.D. Dissertation, Department of Architecture (May).

9 Experimental Work and Modeling of Triple-effect Solar Panel

Figure 41: Test facility for triple-effect solar panel.

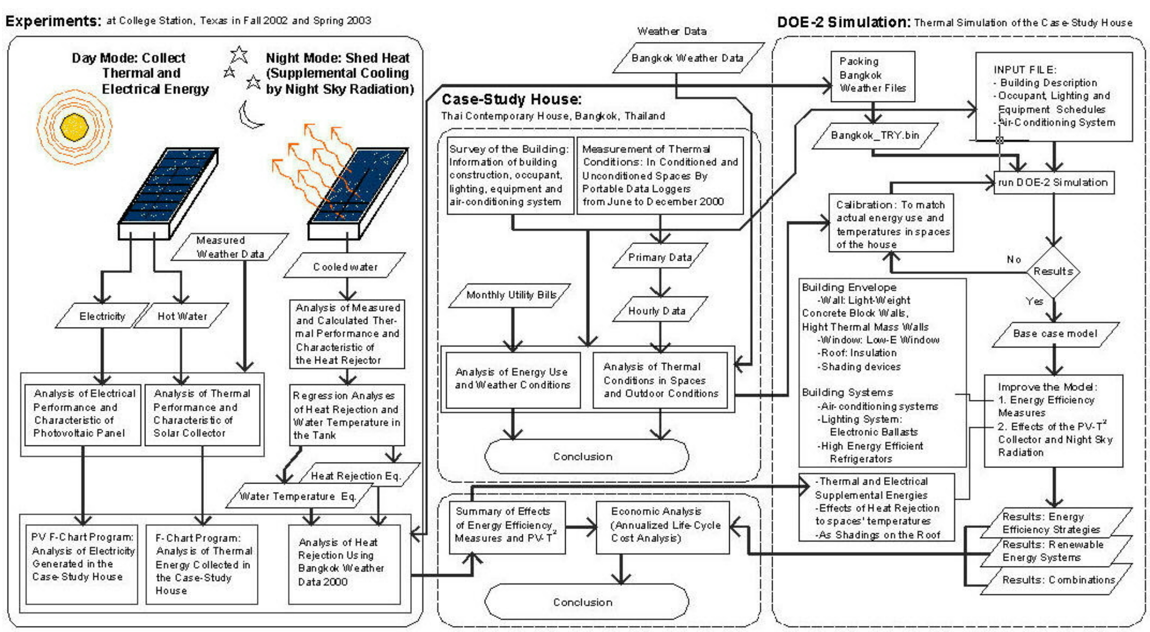

Figure 42: Flowchart of analysis for PVT^2 collector for house in Thailand.

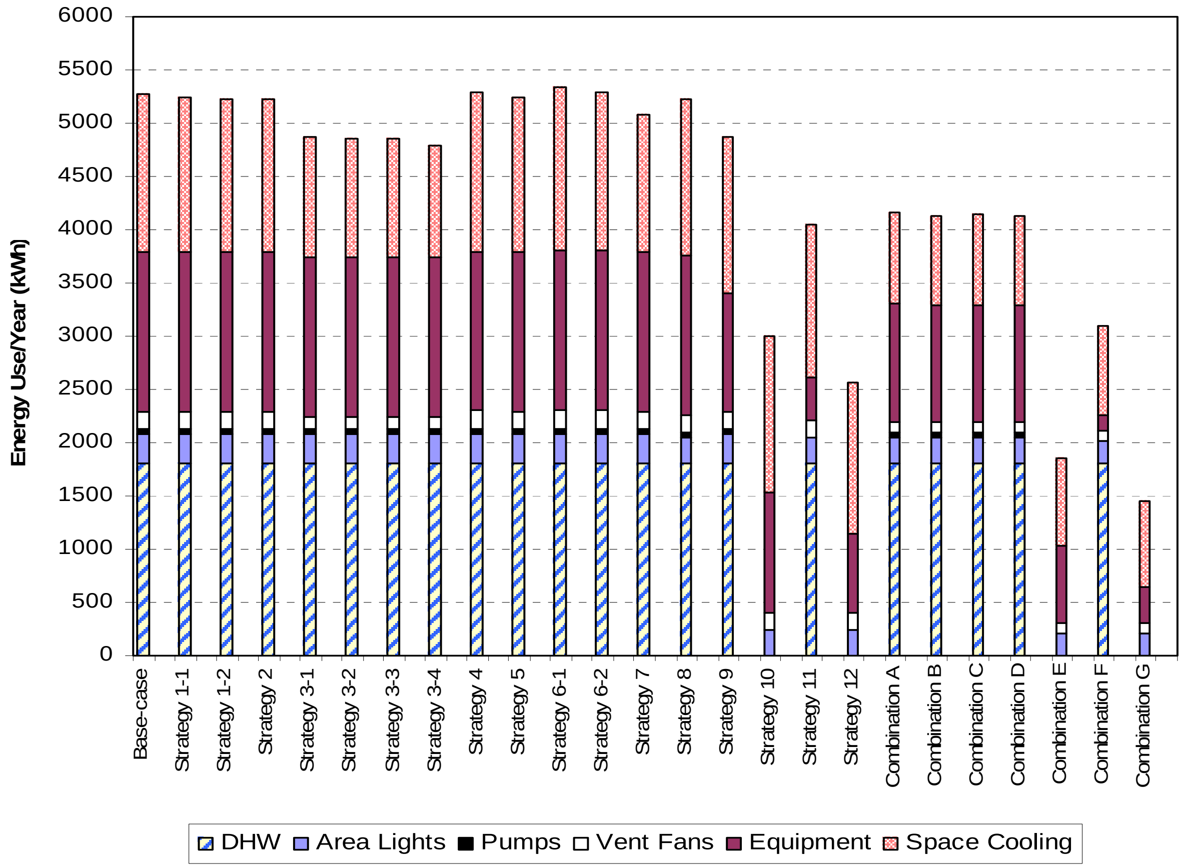

Figure 43: Results of case-study house in Thailand using PVT^2 collector.

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10 Development of Improved Comfort in Unconditioned Buildings in Hot and Humid Climates

Figure 44: Case study temples in Thailand.

Figure 45: Portable instrumentation used in case study temples.

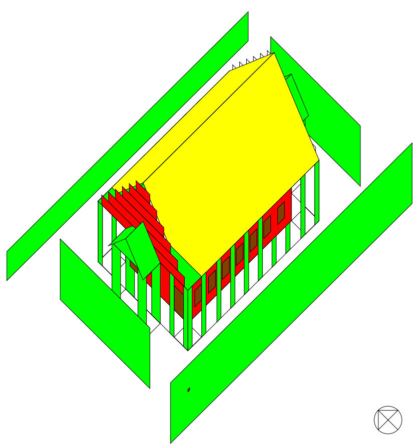

Figure 46: Simulation image of case-study temple.

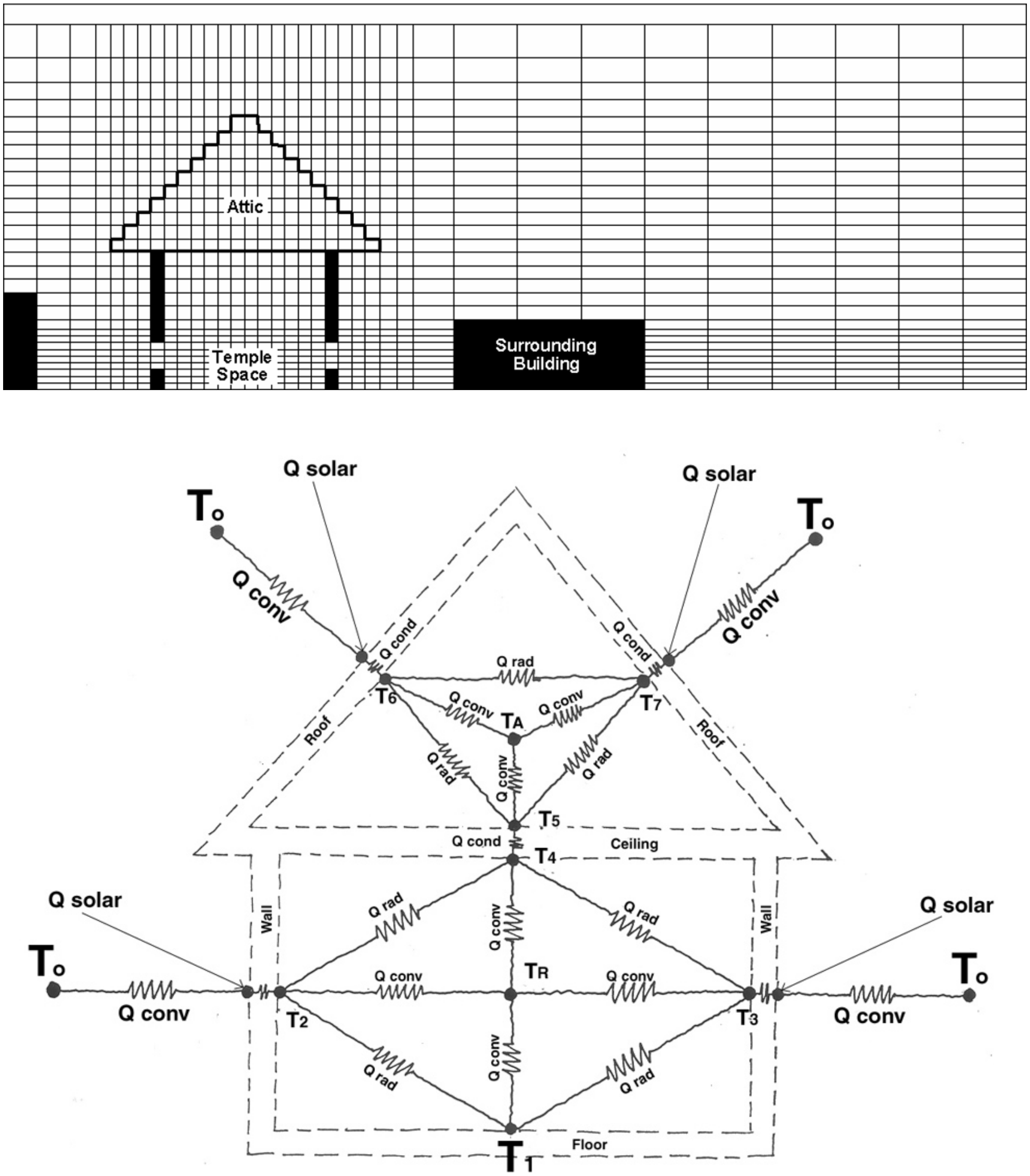

Figure 47: Discrete representation of temple and nodal heat transfer diagram.

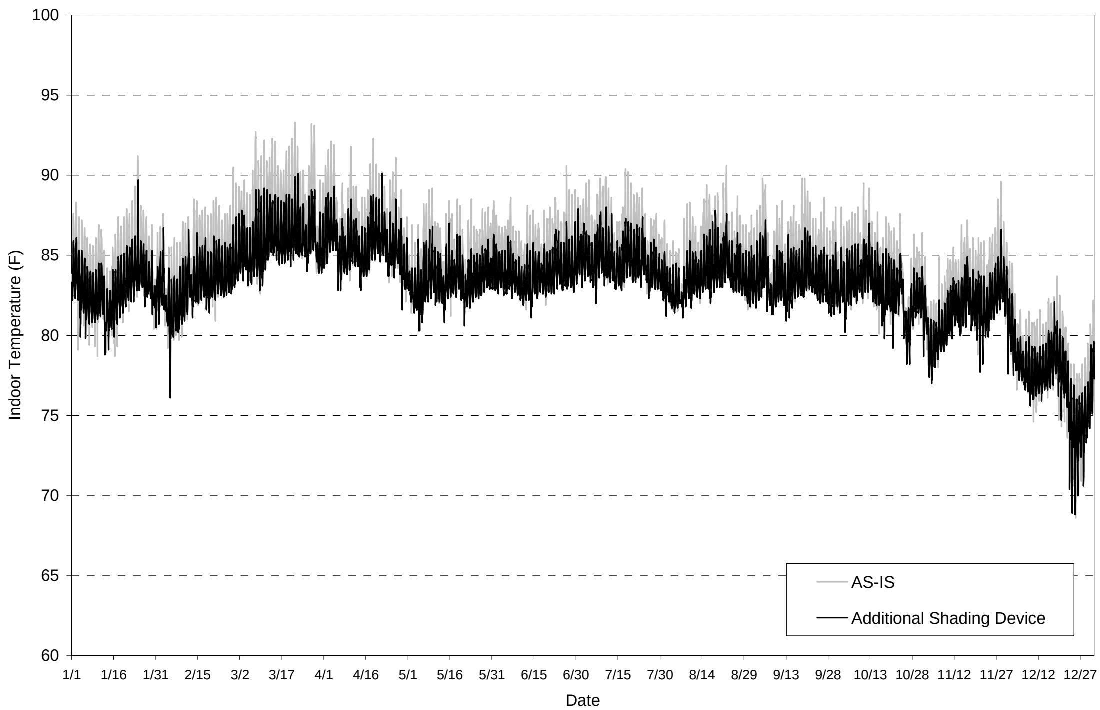

Figure 48: Measured and simulated temperatures for case-study temple.

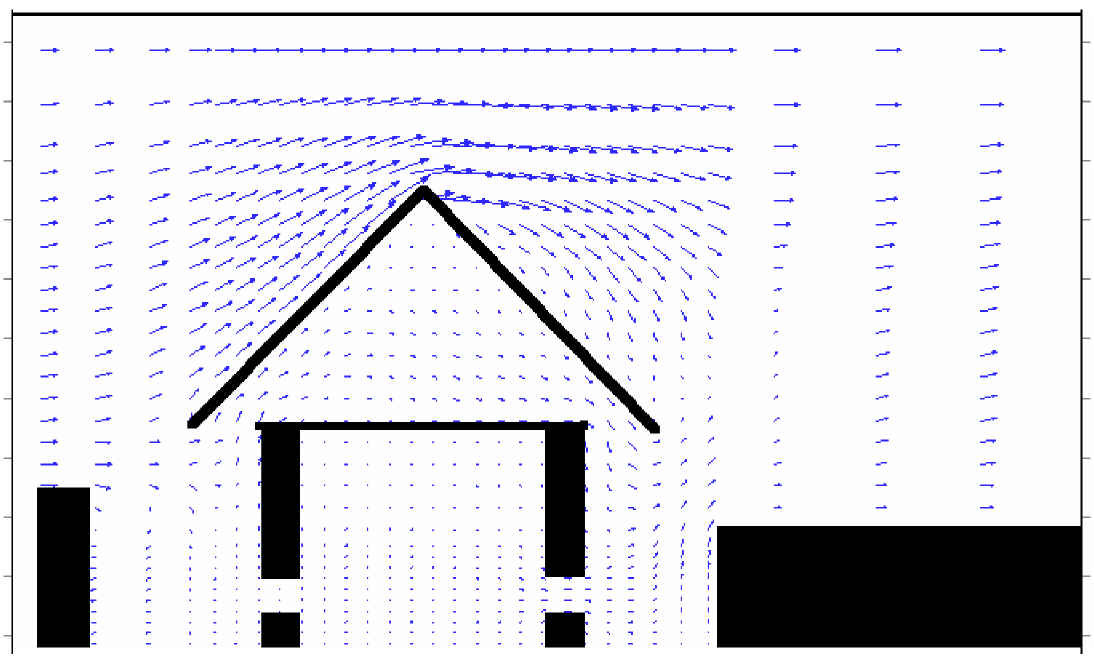

Figure 49: CFD simulation of air flow around case-study temple.

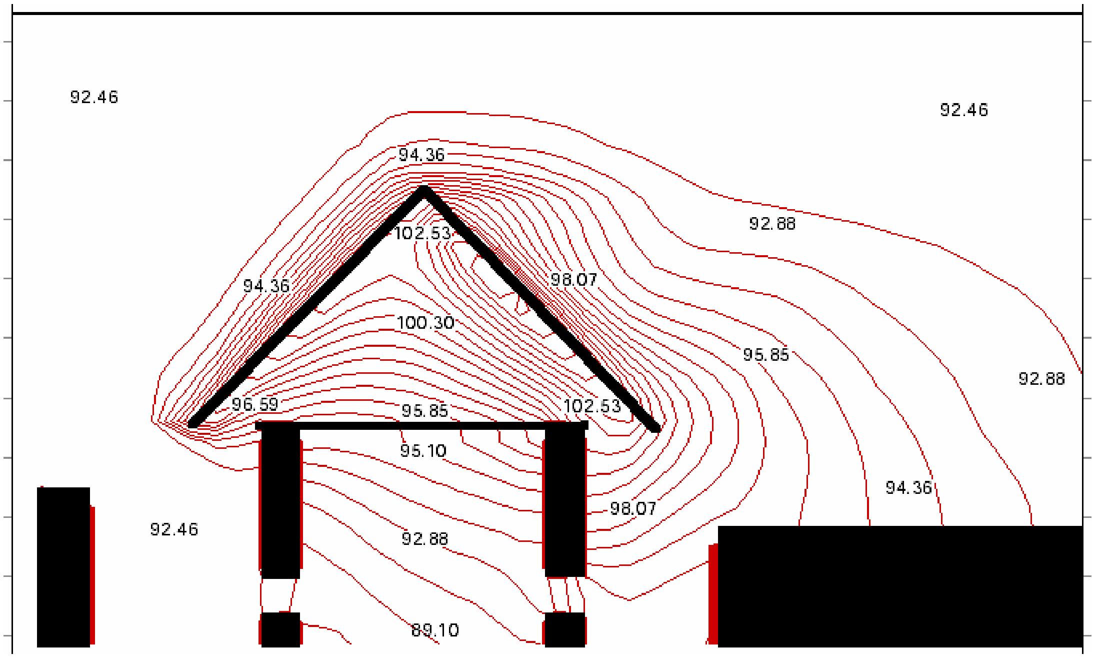

Figure 50: CFD simulation of air temperatures around case-study temple.

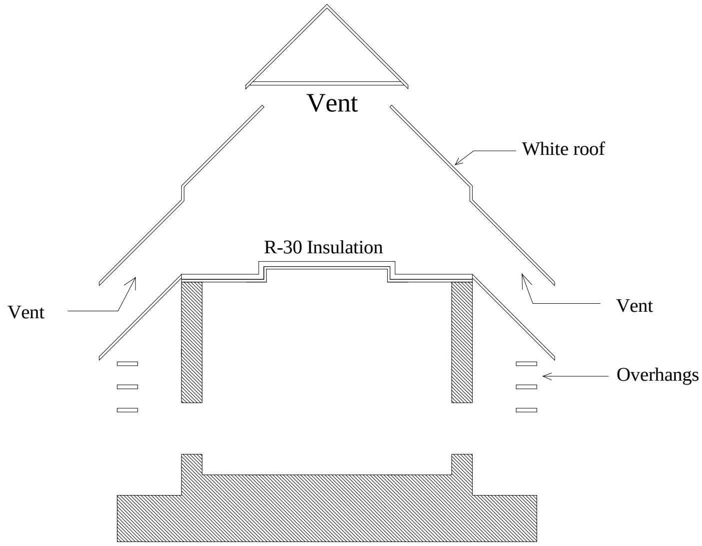

Figure 51: New design for case study temple with improved comfort.

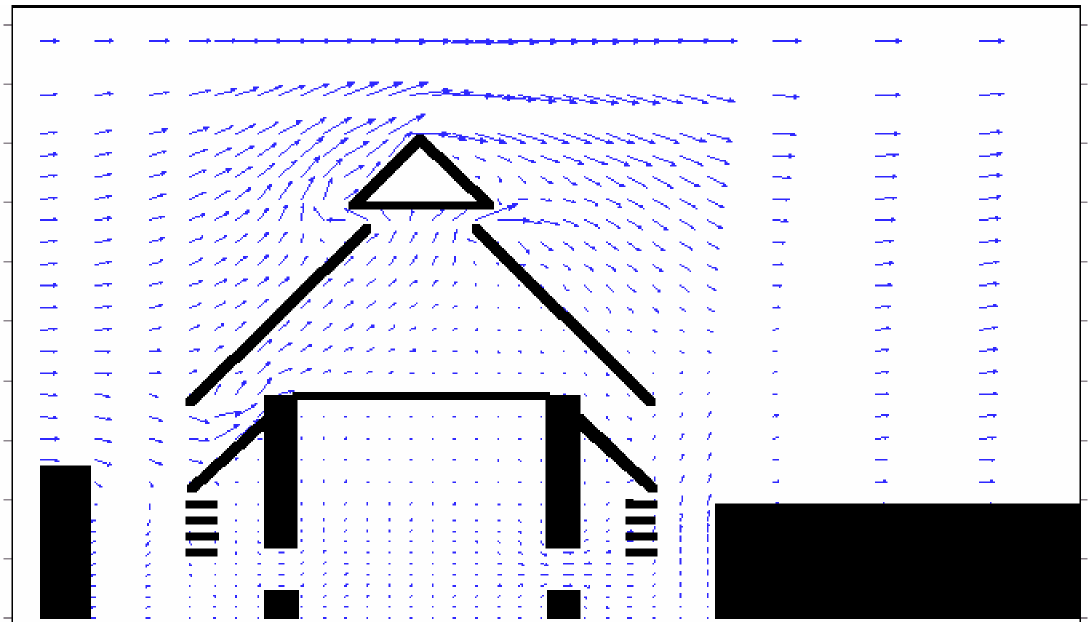

Figure 52: CFD simulation of air flow around new design for case-study temple.

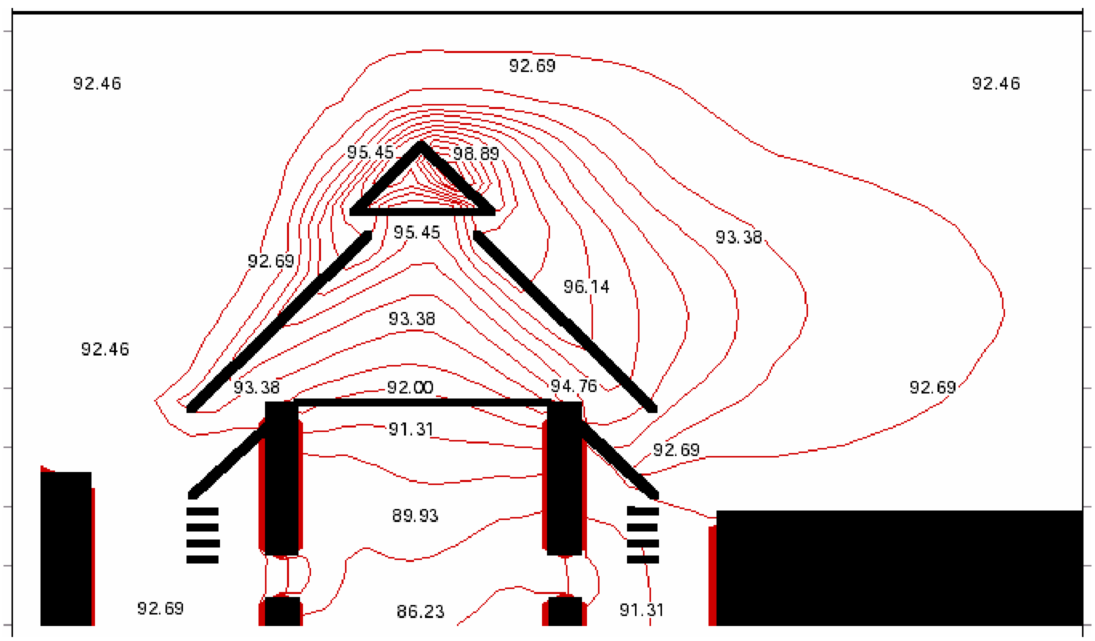

Figure 53: *CFD simulation of air temperatures around new design for case-study temple.*

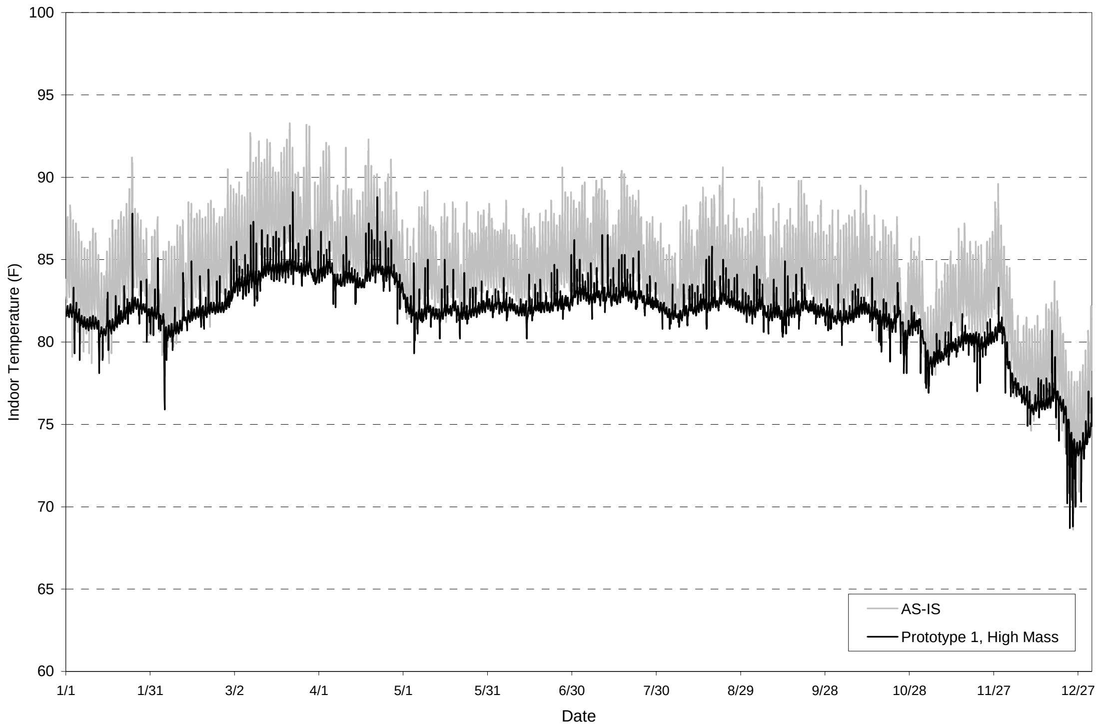

Figure 54: Measured and simulated temperatures for new design for case-study temple.

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11 Research on Cost-effective Low-income Housing, Including Renewable Energy Systems.

Figure 55: Case study house in Thailand.

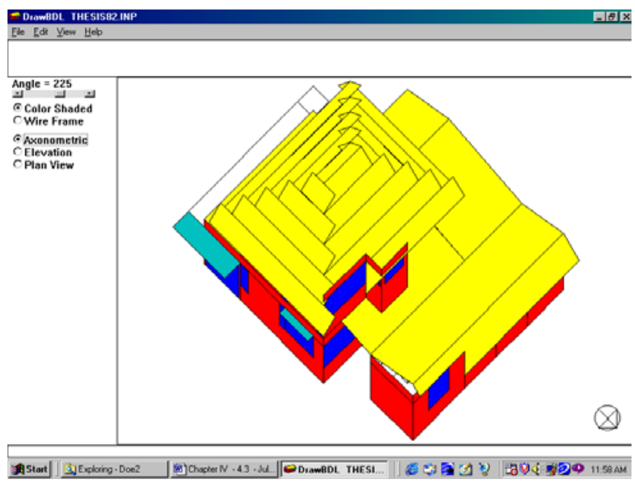


Figure 56: Simulation of case study house in Thailand.

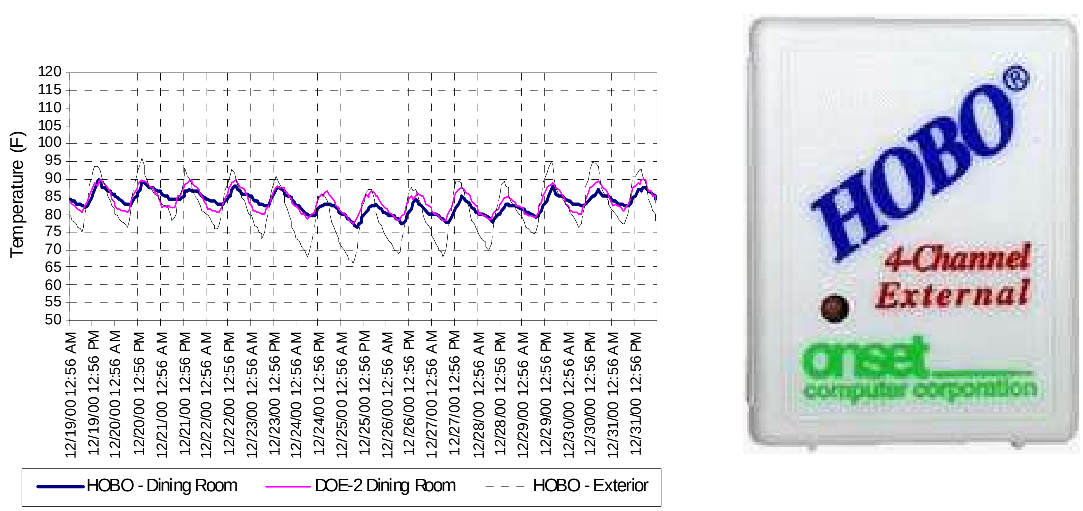
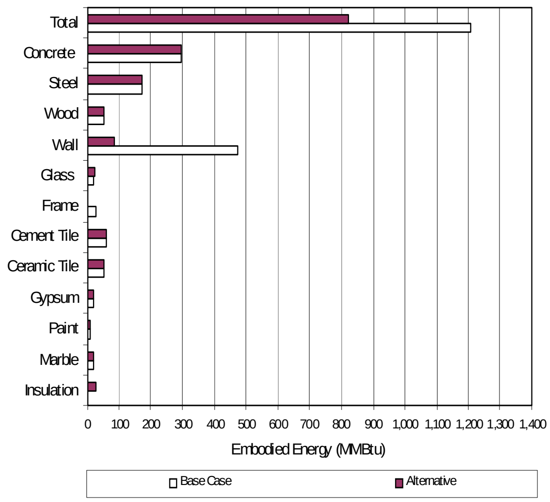
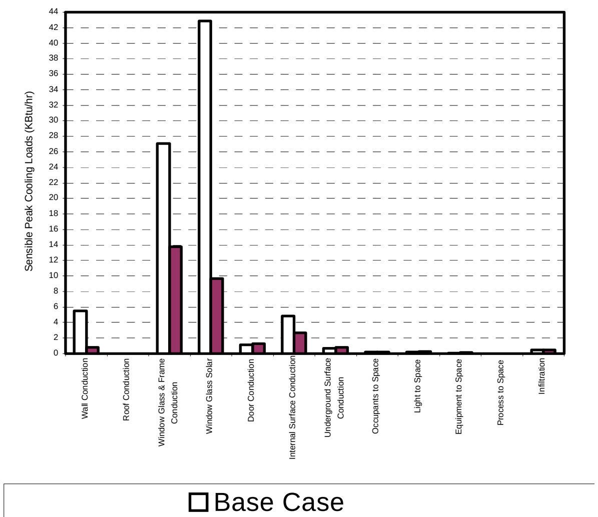
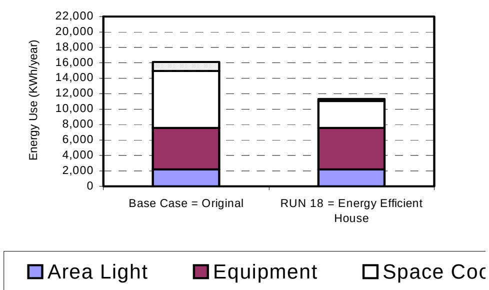


Figure 57: Measured temperatures using matchbook logger.

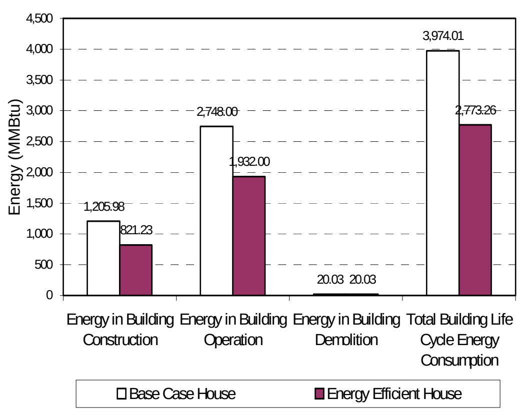


Materials	Embodied Energy (MMBtu)	
	Base Case	New Design
Concrete	296.28	296.21
Steel	171.56	171.56
Wood	52.69	52.69
Wall	**474.64**	**86.27**
Glass	**21.39**	**24.04**
Frame	**27.09**	**0.59**
Cement Tile	57.01	57.01
Ceramic Tile	53.47	53.47
Gypsum	21.60	21.60
Paint	10.08	10.08
Marble	20.17	20.17
Insulation	**0.00**	**27.54**
Total	**1,205.98**	**821.23**





Base Case vs Energy Efficient House		
Energy Use (kWh)	**Base Case**	**RUN 18**
Area Lights	2,227	2,227
Equipment	5,362	5,362
Space Cool	7,377	3,441
Vent Fan	1,143	296
Total	16,109	11,326
Energy Saving (%)	-	29.69



Energy Consumption (MMBtu)	Base Case	New Design
Energy Used in Building Construction	1,205.98	821.23
Energy Used in Building Operation	2,748.00	1,932.00
Energy Used in Building Demolition	20.03	20.03
Lifetime Building Energy Consumption	3,974.01	2,773.26

Figure 58: Results of analysis to reduce total lifetime energy use.

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Figure 59: Case study Habitat for Humanity house, Bryan, Texas.

Figure 60: Sensors used in case-study house.

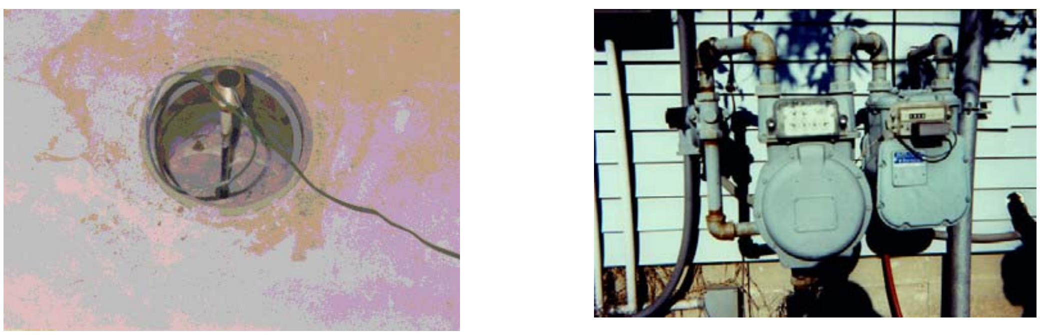

Figure 61: Data logger and natural gas metering.

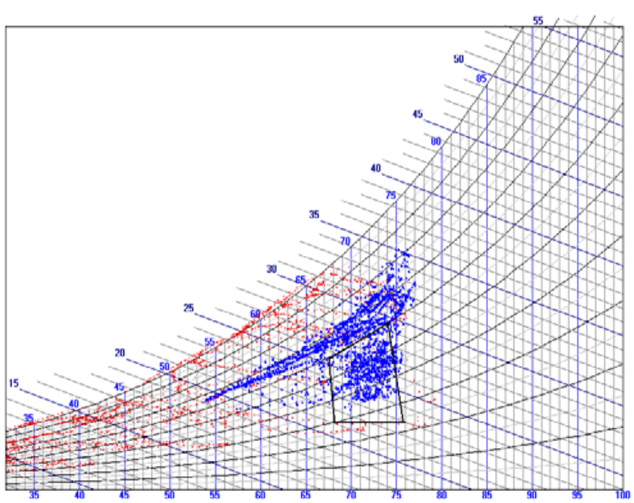

Figure 62: Measured indoor/outdoor temperature and humidity plotted on the psychrometric chart.

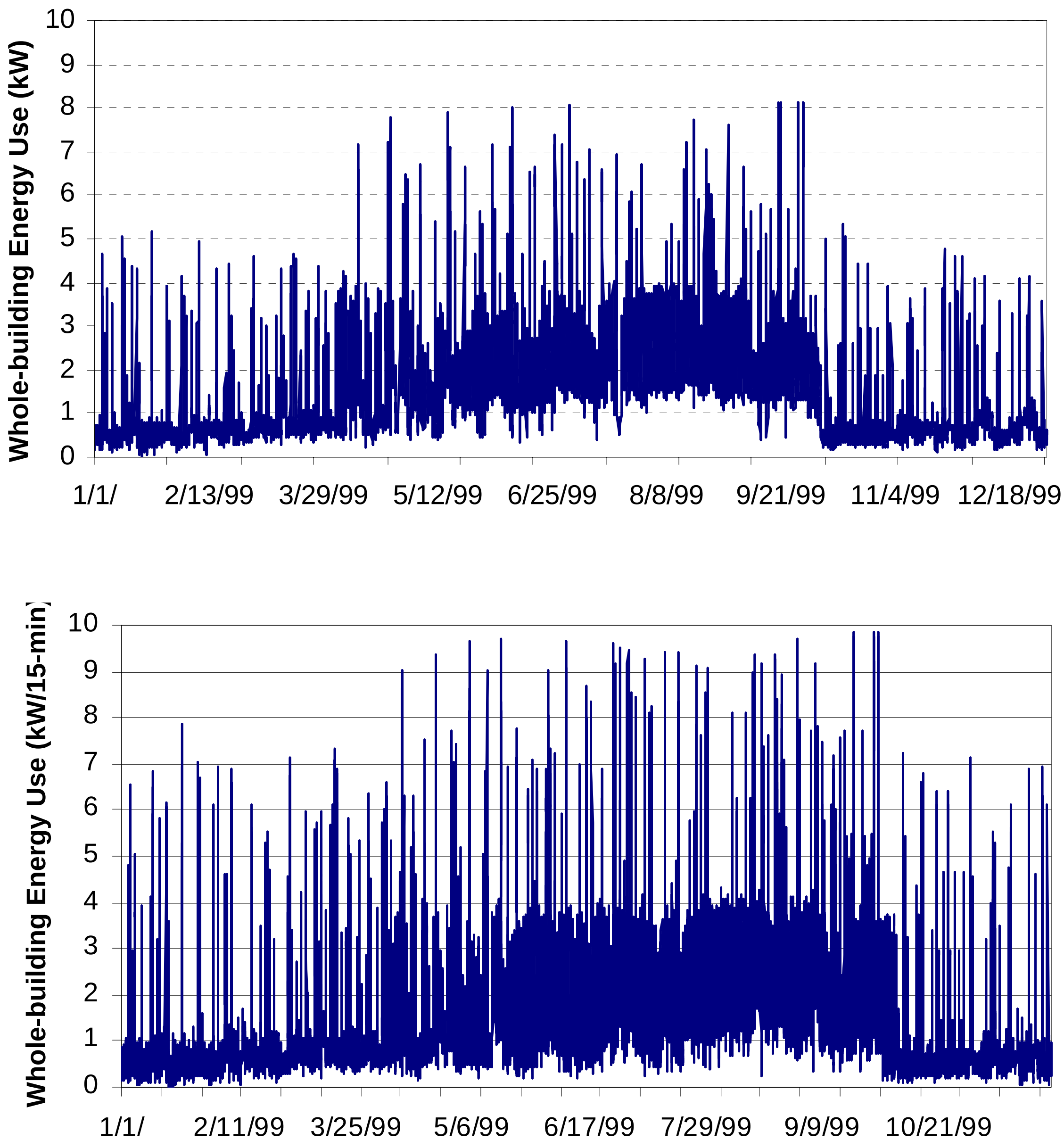

Figure 63: Measured whole-building electricity use (15-minute & hourly).

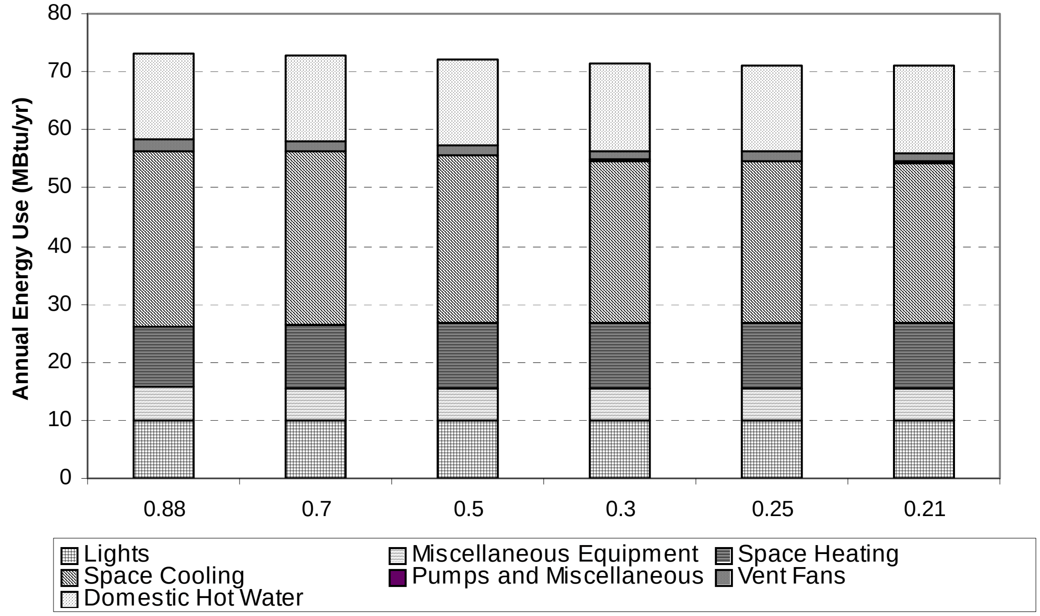

Figure 64: Results of calibrated simulations for varying roof solar absorptance.

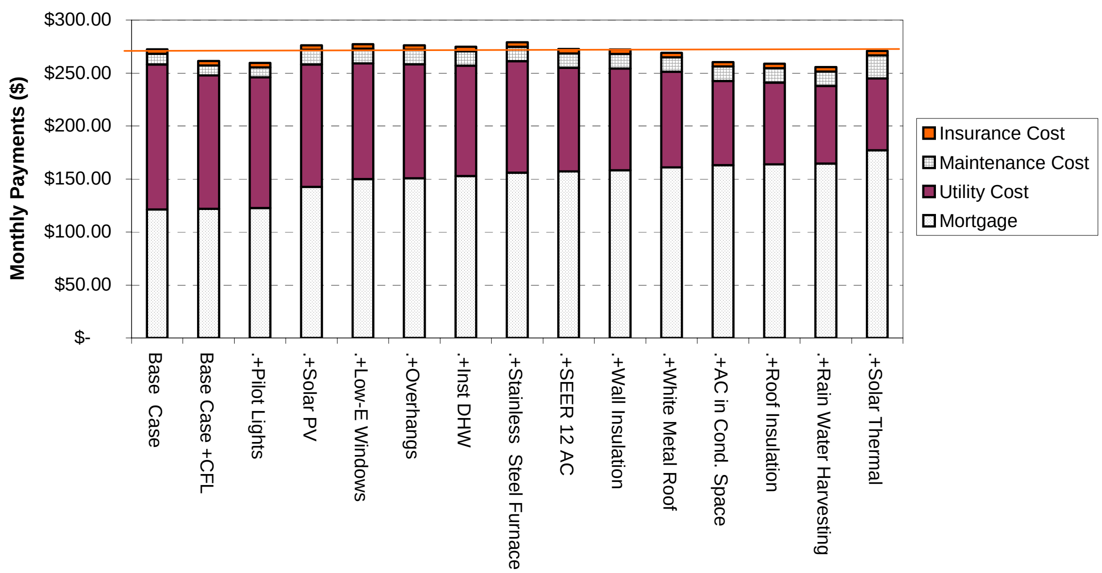

Figure 65: Economic analysis of various energy efficiency measures.

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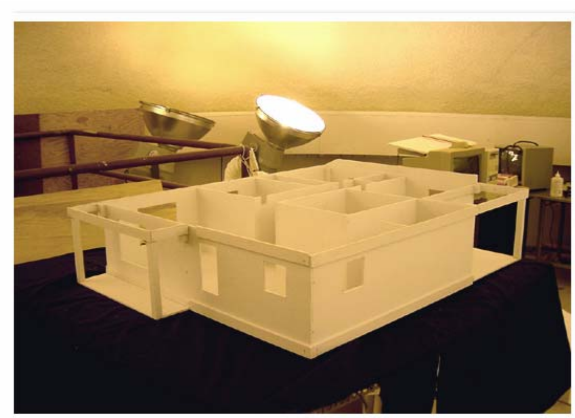
Analysis of Energy Reductions From the use of Daylighting in Low-cost Housing



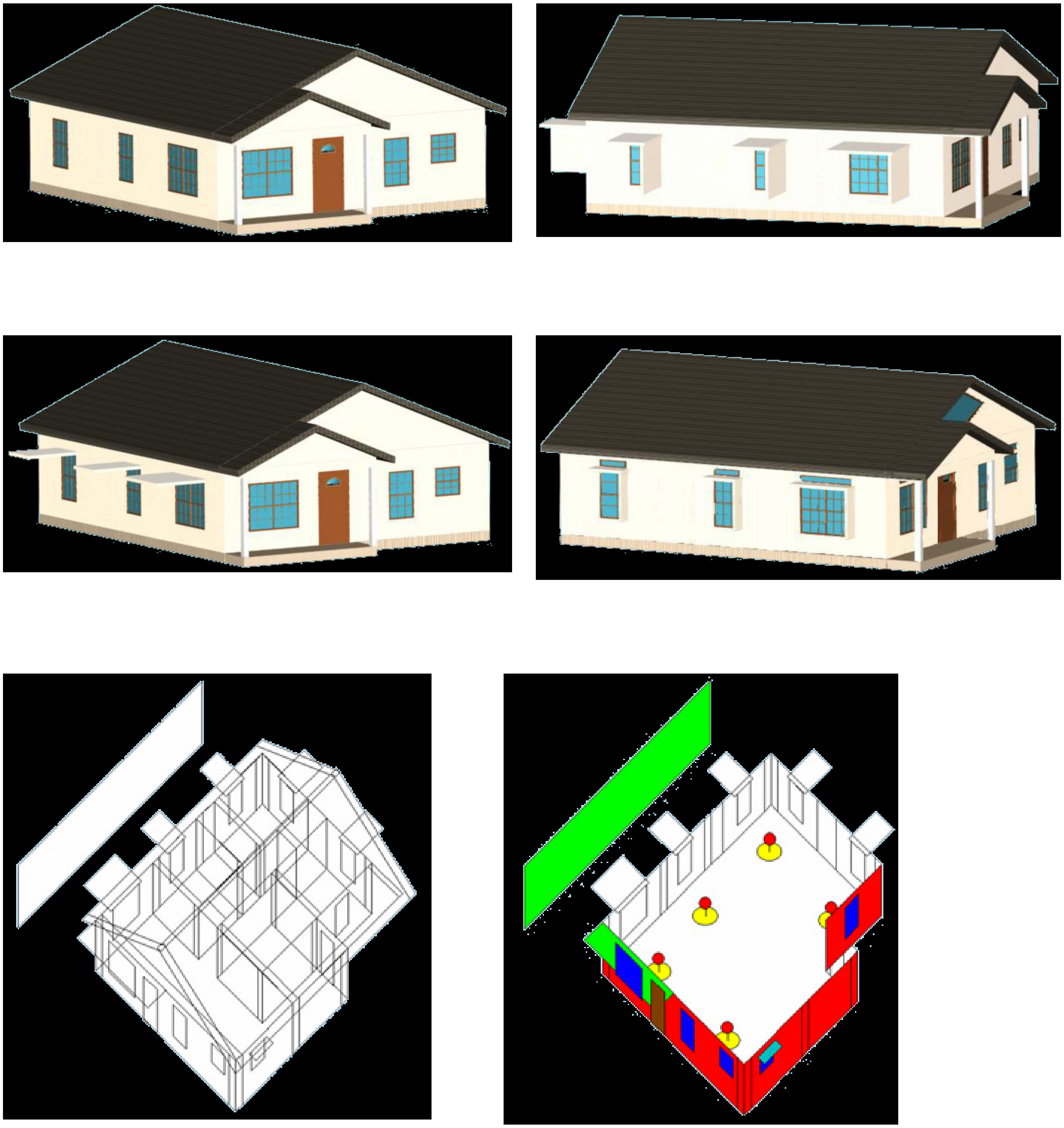


Figure 66: Computer Simulations of different window shading treatments for daylighting analysis.

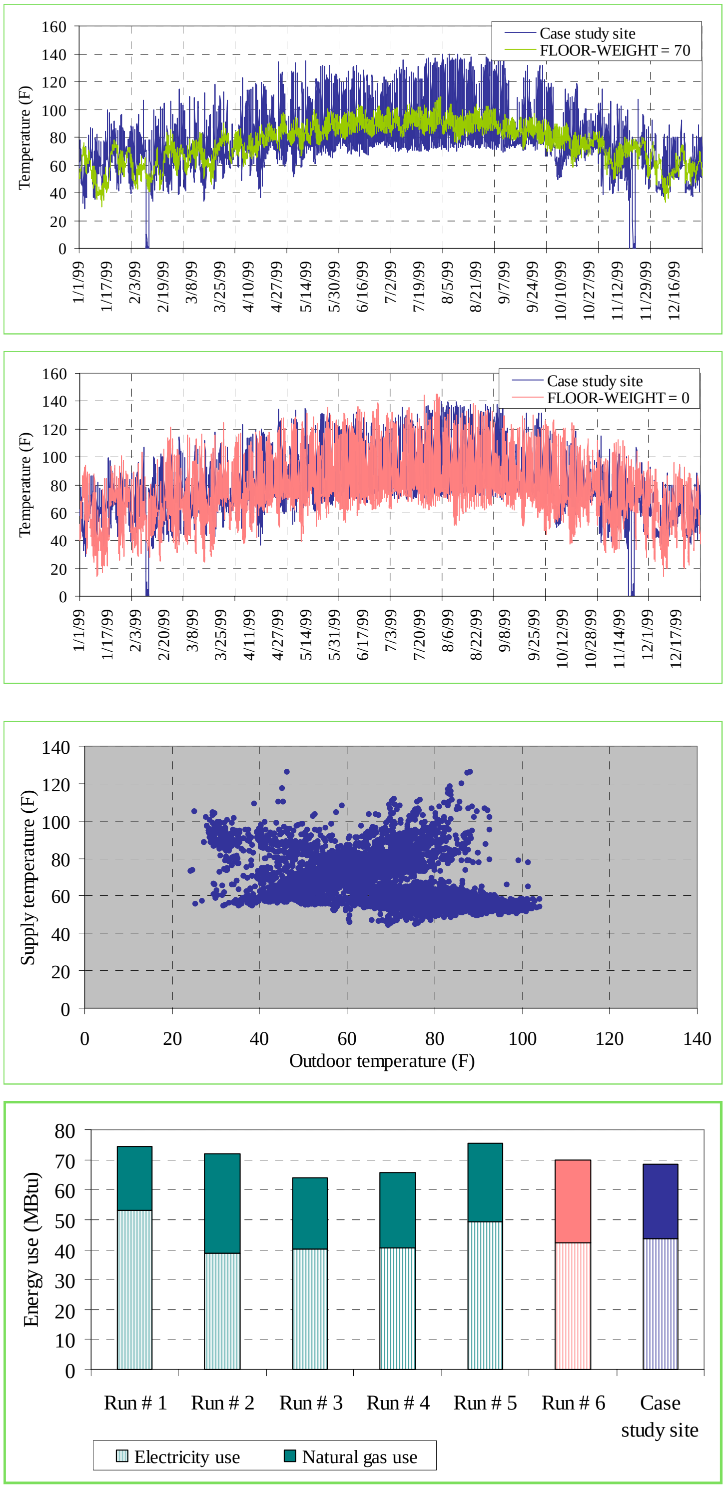


Figure 67: Comparison of measured and simulated data, including results of simulation.

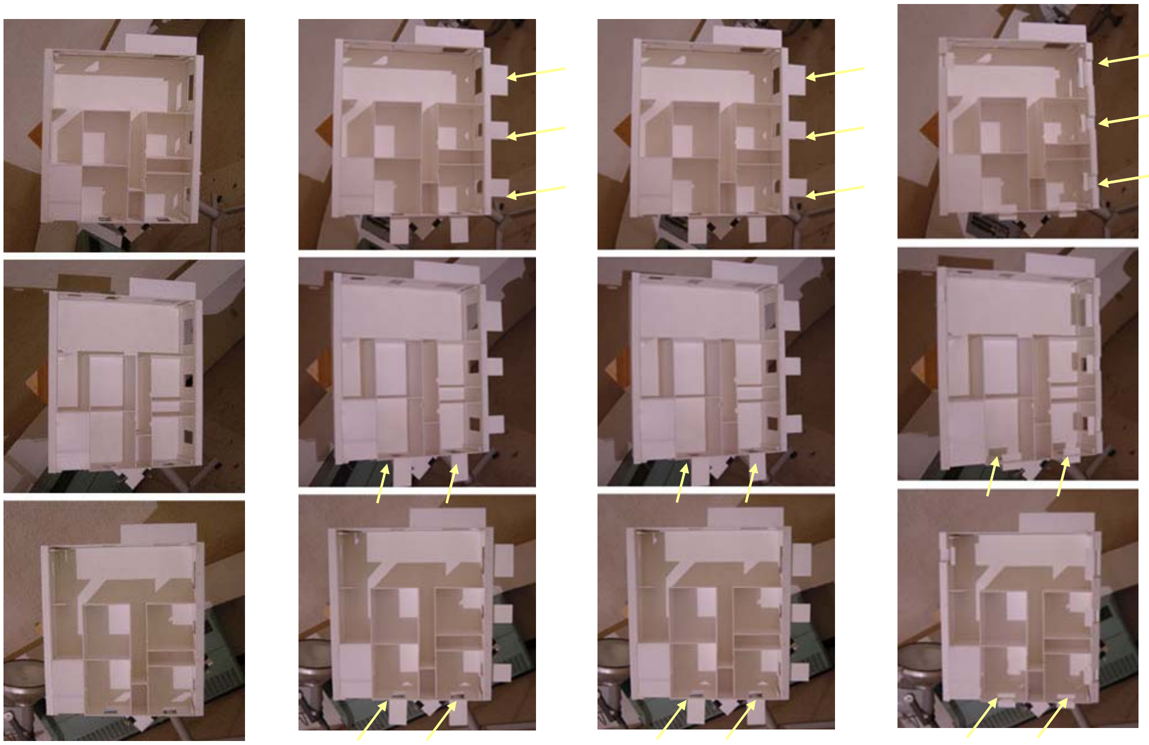
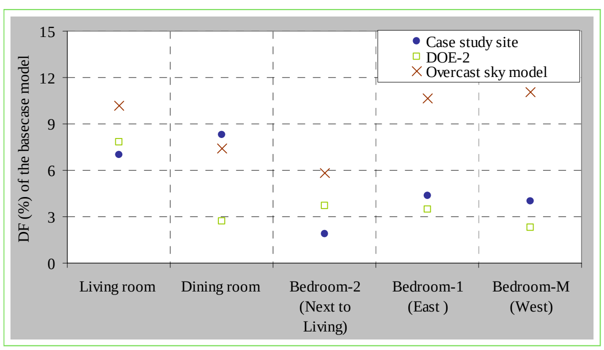


Figure 68: Shadow analysis of direct solar radiation penetration into case-study house: (L-R: base case, overhang, overhand with fins, light shelf).



Location	Difference in DF of Basecase and Lightshelf		Direction of DF Basecase to Lightshelf		Symbol
	Model	DOE-2	Model	DOE-2	
Living	7.2%	-15.2%	Increase	Decrease	
Dining	38.4%	9.6%	Increase	Increase	
Bedroom-2	-10.9%	-41.7%	Decrease	Decrease	
Bedroom-1	-6.6%	-41.5%	Decrease	Decrease	
Bedroom-M	-6.7%	-33.2%	Decrease	Decrease	

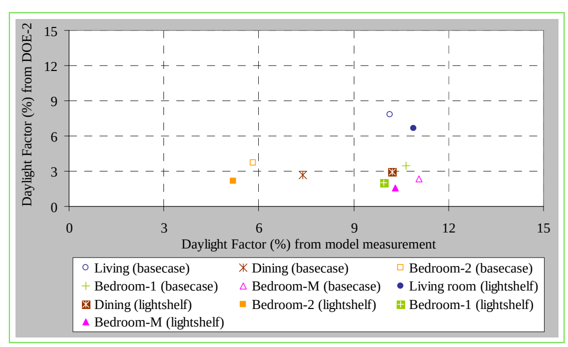
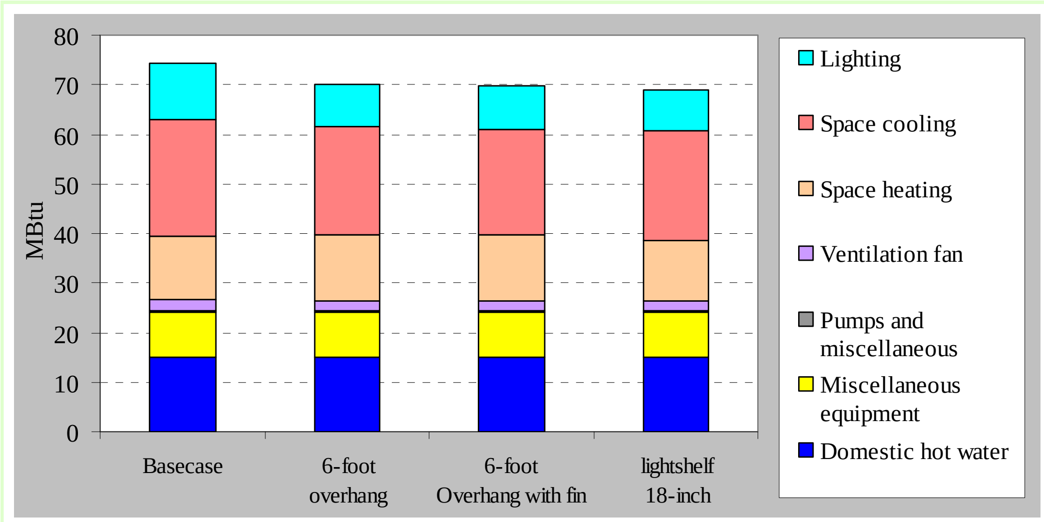


Figure 69: Results From Experimental Model and Simulations (model vs simulation).



Categories (MBtu)	Basecase	6-foot Overhang	Diff (%)	6-foot Overhang w/ fin	Diff (%)	18-inch Lightshelf	Diff (%)
Lighting	11.3	8.5	**24.8**	8.9	**21.2**	8.1	**28.3**
Space cooling	23.6	21.8	**7.6**	21.2	**10.2**	22.1	**6.4**
Space heating	12.8	13.4	**-4.7**	13.3	**-3.9**	12.3	**3.9**
Ventilation fan	2.3	2.1	8.7	2.1	8.7	2.1	8.7
Pumps and misc.	0.2	0.2	0.0	0.2	0.0	0.2	0.0
Misc. equipment	9.2	9.2	0.0	9.2	0.0	9.2	0.0
DHW hot water	14.9	14.9	0.0	14.9	0.0	14.9	0.0
Total energy	**74.3**	**70.1**	**5.7**	**69.8**	**6.1**	**68.9**	**7.3**
Total cost Electriciy + Natural gas							

Figure 70: *Results From Experimental Model and Simulations (annual savings).*

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Rungchareonrat, N. 2003. "An Analysis of Energy Reductions From the Use of Daylighting in Low-cost Housing", Master's Thesis, Department of Architecture, Texas A&M University (August).

12 Conferences Sponsored by the Energy Systems Laboratory

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