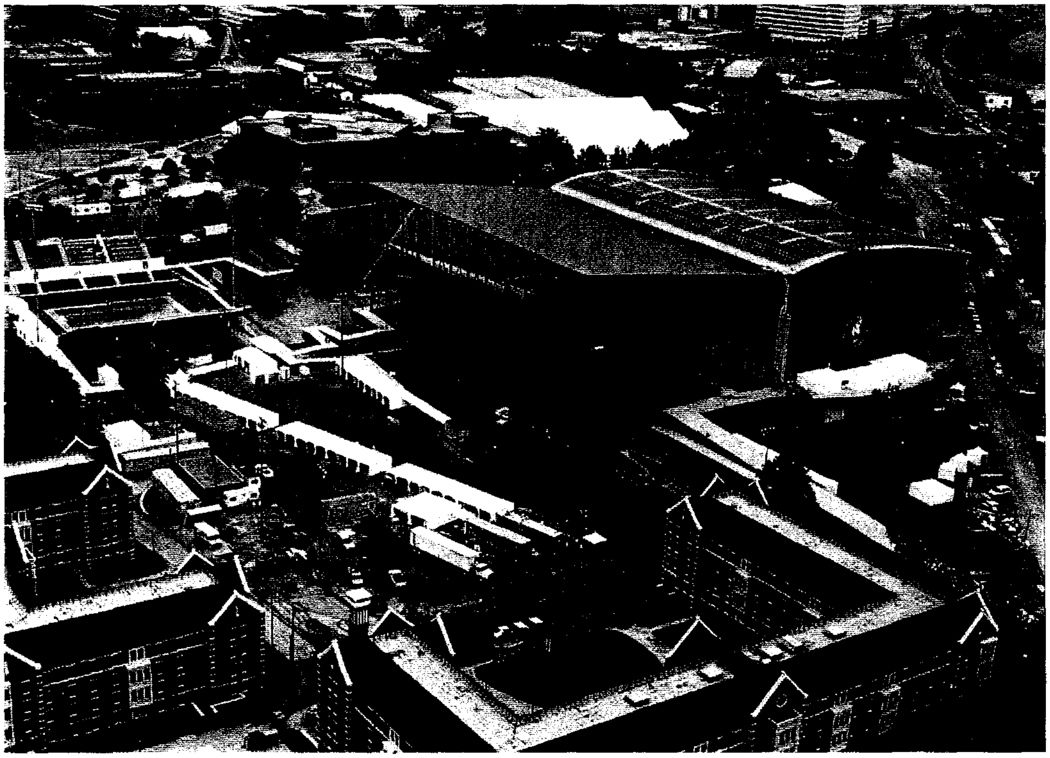
RECEIVED
AUG 13 1998
OSTI

VOLUME ONE

THE DESIGN, CONSTRUCTION, AND MONITORING OF PHOTOVOLTAIC POWER SYSTEM AND SOLAR THERMAL SYSTEM ON THE GEORGIA INSTITUTE OF TECHNOLOGY AQUATIC CENTER

DOE/GO/10019--T1-Vol. 1



Aerial Photo - Site Construction Preparing Aquatic Center for 1996 Summer Olympic Games

RICHARD C. LONG, AIA
Principal Investigator
Author

AJEET ROHATGI
Professor - College of Electrical and Computer Engineering
Co-principal Investigator

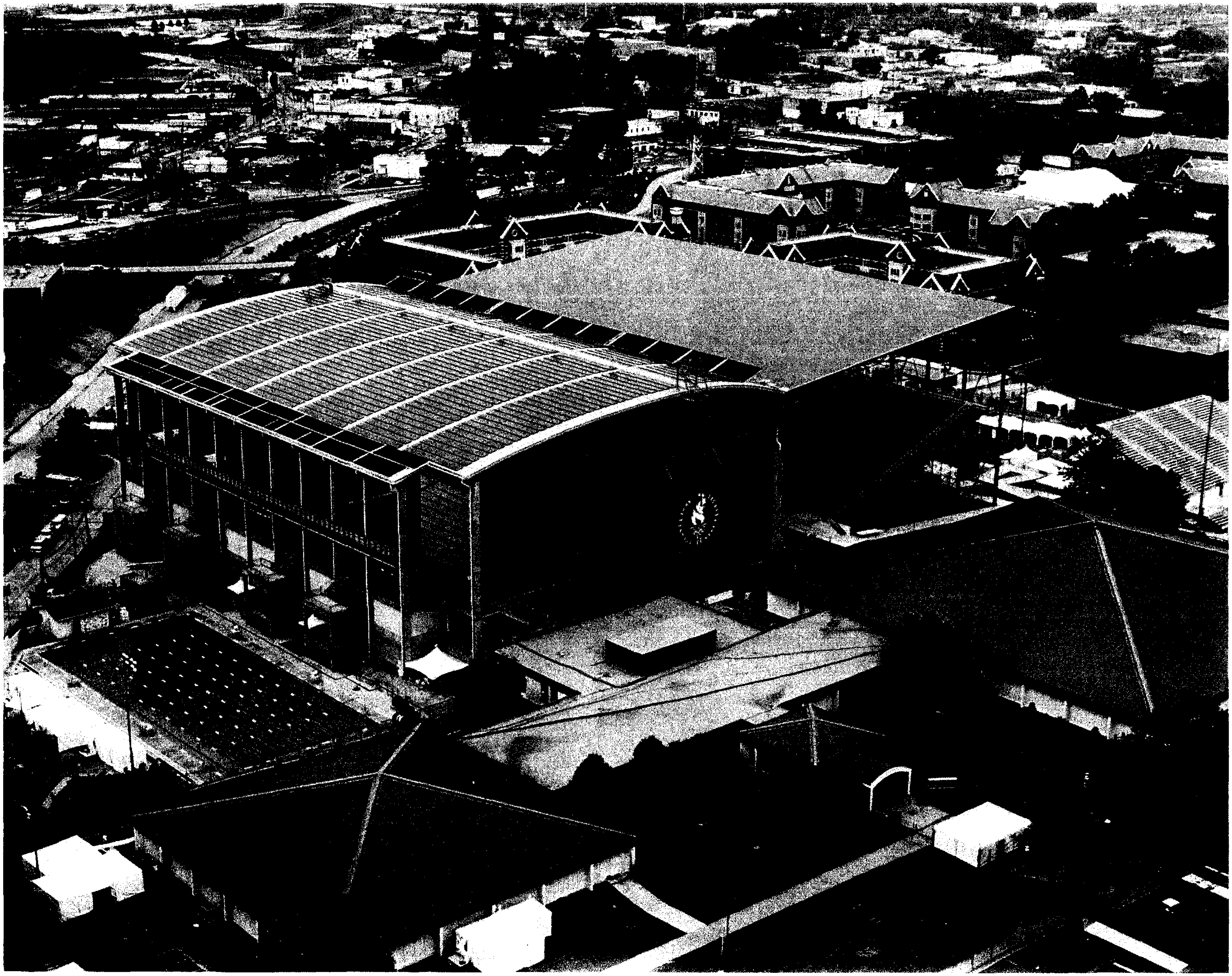
MIROSLAV BEGOVIC
Professor - College of Electrical and Computer Engineering
Co-principal Investigator

MIKE ROPP
Ph.D. Student
Co-principal Investigator

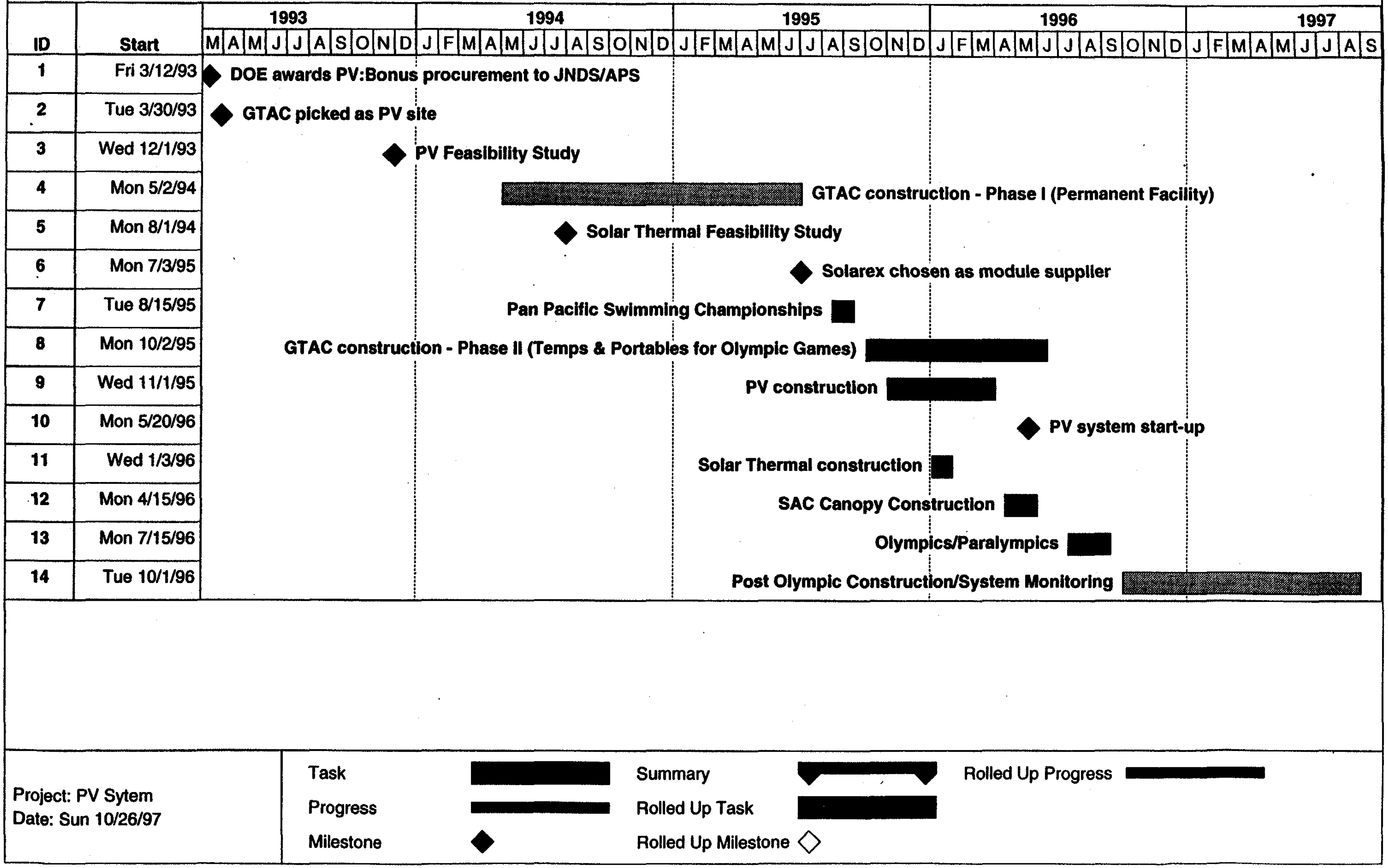
JENNIFER ADAMS
Undergraduate Student
Editor

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED



Georgia Institute of Technology Aquatic Center Photovoltaic/Solar Thermal Project Schedule



Project: PV Sytem
Date: Sun 10/26/97

MAJOR ENTITIES INVOLVED IN PRODUCING THE PHOTOVOLTAIC ARRAY

ENTITY	ROLE(S)
Advanced Photovoltaic Systems (now defunct) Ron Matlin	• First photovoltaic module supplier • Partnership with JND Sterling to respond to PV:Bonus program
The Whiting-Turner Contracting Company Keith Douglas 2300 Windy Ridge Pkwy, Suite 155-S Atlanta, GA 30339 (770) 955-9300	• Design/Build contractor for the Georgia Tech Aquatic Center and the PV system
Georgia Institute of Technology Richard Long, Principal Investigator 225 North Avenue, NW 4th Floor Administration Building Atlanta, GA 30332 (404) 894-3554	• Site of PV System (Georgia Tech Aquatic Center) • Financial sponsor of Georgia Tech Aquatic Center structural upgrades and permanent roof for PV system
Georgia Power Company Chuck Huling 333 Piedmont Avenue Atlanta, GA 30308	• Local utility company • Financial sponsor of PV system • Co-sponsor of PV:Bonus incentive program (with US Department of Energy)
Heliocol USA Victor Eyal 927 Fern Street, Suite 200 Altomonte Springs, FL 32701 (407) 831-1941	• Solar thermal system supplier (Appendix A)
Programmed Media Environments Robert Forstrom PO Box 569 Glen Cove, NY 11542-0569	• PV system consultant
Roger Preston + Partners (Formerly JND Sterling) Daniel Nall 1050 Crown Pointe Pkwy, Suite 1100 Atlanta, GA 30338 (770) 394-7175	• PV system engineering integrator • Partnership with Advanced Photovoltaic Systems to respond to PV:Bonus program
Rosser Ron Mitchell 524 West Peachtree Street, NW PO Box 54680 Atlanta, GA 30308-0680 (404) 888-6924	• Architect for the Georgia Tech Aquatic Center PV system
Solar Design Associates Steven Strong Harvard, MA 01451-0242 (508) 456-6855	• SAC Canopy PV Mockup system engineering integrator (Appendix B)

ENTITY	ROLE(S)
Solarex William Rever 630 Solarex Court Frederick, MD 21701 (301) 698-4208	• Final photovoltaic module supplier
Southwest Technology Development Institute Steven Durand New Mexico State University Las Cruces, NM 88003-8001 (505) 646-1514	• Data Acquisition System design and installation
Trace Technologies (Formerly Kenetech Windpower) PO Box 5049 Livermore, CA 94551-5049	• Inverter supplier
US Department of Energy James Rannels 1000 Independence Avenue SW Washington, DC 20585 (202) 586-1720	• Financial sponsor of PV and solar thermal systems • Co-sponsor of PV:Bonus incentive program (with Georgia Power Company)
Beacon Sales Corporation Merchant & Evans, Inc. Zip-Rib® product William E. Watts, Jr. PO Box 8664 Jacksonville, FL (904) 743-9770	• Roof and PV module installation subcontractor to Whiting-Turner

ABBREVIATIONS KEY

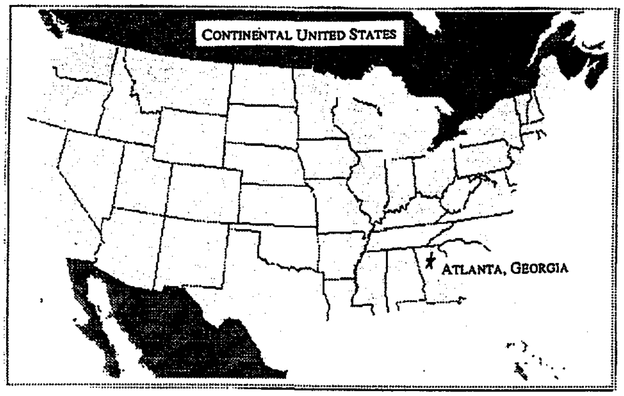
ACOG	Atlanta Committee for the Olympic Games
APS	Advanced Photovoltaic Systems
DAS	Data Acquisition System
DOE	United State Department of Energy
GPC	Georgia Power Company
GTAC	Georgia Tech Aquatic Center
PV	Photovoltaic
RFQ	Request for Qualifications
STS	Solar Thermal System
UCEP	University Center for Excellence in Photovoltaic Research

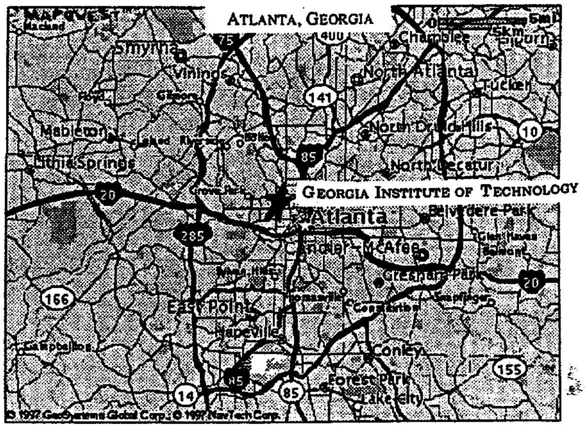
TABLE OF CONTENTS

I. INTRODUCTION

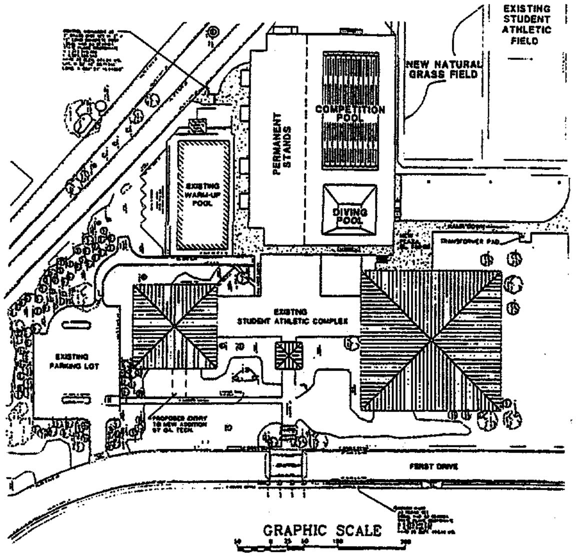
What is the Georgia Tech Aquatic Center?

The Georgia Institute of Technology campus hosted the Olympic Village, natation, and boxing venues for the 1996 Centennial Olympic Games as well as the Paralympic Village and natation venue for the 1996 Paralympic Summer Games. In preparation for the Games, construction began on the natation venue known as the Georgia Tech Aquatic Center (GTAC) in June 1994. GTAC was designed as a world class facility that was the first to combine all Olympic aquatic events at one venue. Thus during the Olympic Games, spectators were able to view the swimming portion of the modern pentathlon, water polo, diving, swimming, and synchronized swimming competitions at the venue. Although the pool used for water polo preliminary competition was temporary, the remaining aquatic venue is a 112,000 gross square foot open-air structure capped by its roof rising 95 feet above the pool deck.





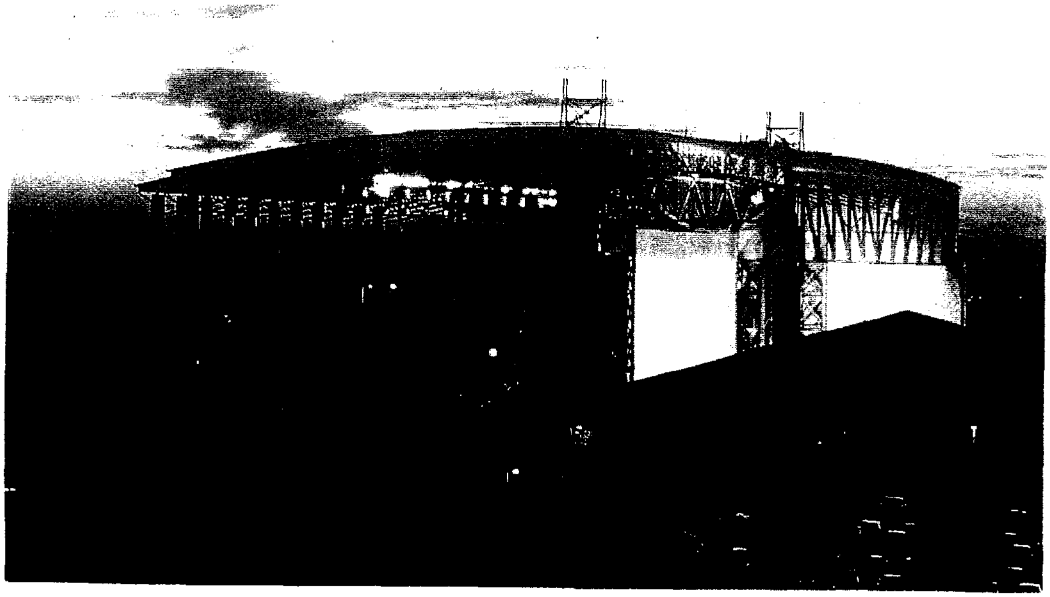
GEORGIA TECH AQUATIC CENTER SITE PLAN



The facility boasts:

- 25m x 25y diving well
- 5 diving platforms
- 3 permanent springboards
- 25m x 52m (10 lanes) competition pool
- 2 moveable bulkheads
- adjustable floor depth
- 2,000 permanent seats
- capacity for 11,000 temporary seats used during the Olympics and Paralympics
- 58 world records

The expanse of the venue today leaves its indelible mark on the Atlanta skyline.

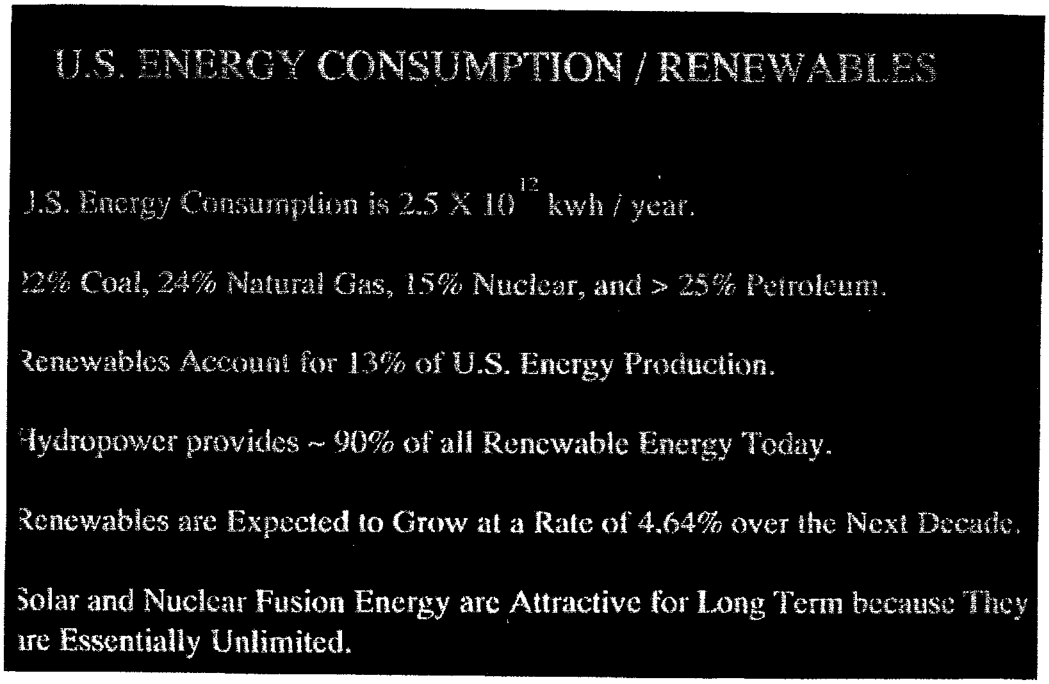


The Atlanta Committee for the Olympic Games (ACOG) originally planned the GTAC roof to be temporary. However, the Georgia Institute of Technology contributed funds to upgrade the columns and trusses of the structure to support a permanent roof. This allows Georgia Tech the option of completely enclosing the facility for year-round use.

Why install a photovoltaic system?

The world's natural resources continue to be depleted in direct proportion to its population increase. Low energy prices have induced complacency among consumers, especially in affluent western countries. In many countries of the third world, per capita energy consumption does not exceed 5 percent of that in the US. Since the world population is expected to grow by half of its percent number during the next 25 years, patterns of consumption will be driven by these third world countries.

Among the new technologies being developed in the advanced countries, photovoltaics (PV) have become increasingly attractive due to the advances in efficiency and decrease in the production cost of the new panels. According to some studies, covering 1.5% of the territory of the US with PV panels would generate enough energy to satisfy national consumption. However, PV-generated power continues to cost approximately 25 cents/kWh whereas fossil fuel power costs only 8 cents/ kWh.



U.S. ENERGY CONSUMPTION / RENEWABLES

U.S. Energy Consumption is 2.5 X 10^{12} kwh / year.

22% Coal, 24% Natural Gas, 15% Nuclear, and > 25% Petroleum.

Renewables Account for 13% of U.S. Energy Production.

Hydropower provides ~ 90% of all Renewable Energy Today.

Renewables are Expected to Grow at a Rate of 4.64% over the Next Decade.

Solar and Nuclear Fusion Energy are Attractive for Long Term because They are Essentially Unlimited.

Why was GTAC chosen as the site for a PV system?

In 1993, the US Department of Energy initiated a PV:Bonus program. The program intent was to develop and promote cost effective commercial photovoltaic applications in the US residential, commercial, and institutional building sectors. For this program, $25 million were allocated by the US Department of Energy. Georgia Power Company then agreed to participate on a matching funds cost share basis with DOE for qualifying projects in Georgia. In response to the Department of Energy's call for PV:Bonus projects, Advanced Photovoltaics Systems (California), a PV module (thin film/amorphous silicone) supplier, and JND Sterling, an engineering firm, developed the idea of showcasing PV technology in the Olympic Games. Many sites were considered, but GTAC was finally chosen to be the site for a 45,000 square foot photovoltaic system.

The Natation Venue saw 25,000 spectators enter during each day of Olympic competition. As the most televised venue of the Games, the Georgia Tech Aquatic Center was also host to the media of 197 countries. The sheer volume of international exposure made GTAC the perfect showcase for the advancement of renewable energies technology in support of President Clinton's Climate Change

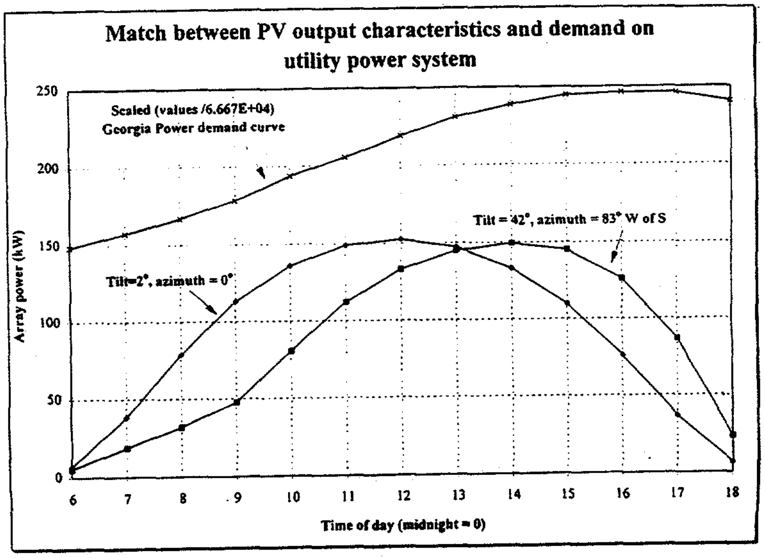
Action Plan. In addition to the optimum chance for media exposure, the campus of Georgia Tech provided some of the best monitoring, testing, and evaluation facilities in the country with the existence of one of the US Department of Energy's University Centers for Excellence in Photovoltaic Research and Education (UCEP) within the Georgia Tech School of Electrical and Computer Engineering. UCEP has excellent facilities and capabilities for conducting research in the areas of PV materials, design and fabrication of PV devices, and testing of solar cells. The marriage of the vast exposure of the Olympics and on-site expertise available to create the system produced the largest grid-connected photovoltaic array in the world at the time GTAC was constructed.

What are the components of the PV system?

In an effort to support PV technology, Georgia Tech, Georgia Power Company, and the US Department of Energy sponsored a 340 kilowatt roof-mounted photovoltaic array. The system utilizes 2,832 Solarex polycrystalline modules. Energy collected by the modules is fed as direct current into an inverter in the GTAC mechanical room which renders the power useful for the electrical load at GTAC. As the highest structure in the area, the PV modules were subject to lightning strikes which could seriously decrease output of the system. Thus a lightning protection system was installed. Additionally, in order to monitor the output and climatic conditions of the PV system, a data acquisition system was installed.

What is the objective of the PV system?

The system was designed to reduce the electric peak burden on the local utility (GPC) by 30%. Thus, the system does not seek to provide the best efficiency year round, but the greatest efficiency during only the months when local electricity demand is high (the summer months). Because local electric demand is weather driven (driven by the need for air conditioners in the summer) and the sun's energy is strongest during the summer months, the PV system automatically produces its maximum energy when local demand is at a peak.



Match between PV output characteristics and demand on utility power system

II. FUNDING

The Georgia Tech Aquatic Center base facility, funded by the Atlanta Committee for the Olympic Games, cost $21 million. In addition, the Georgia Institute of Technology contributed $1,569,607 to upgrade the facility with a permanent roof. Georgia Tech also contributed $136,012 for change orders to the PV contract. As co-sponsors of the PV system, the US Department of Energy supplied $1,993,000 for the PV system (in addition to change orders for the solar thermal system - see Appendix A), and the Georgia Power Company contributed $1,848,000 for the PV system. For an itemization of actual costs, see section VI.

Total Cost of GTAC Project

Base Facility	$	21,000,000
Permanent Roof	$	1,569,607
PV System	$	3,841,000
Solar Thermal System	$	154,973
TOTAL COST	$	***26,565,580***

In December 1993, the engineering integrator for the PV project, JND Sterling produced a feasibility study. The scope of work for the study was described as the following:

> "a conceptual feasibility study for the application of photovoltaics to the Georgia Institute of Technology Natatorium; schematic design support for the Natatorium design team; and a protocol for monitoring, testing and performance verification of the photovoltaic system.
>
> ...designed to assist The Georgia Power Company and The Georgia Institute of Technology in their decision to further support the photovoltaic system's implementation. To that end, several project-specific issues are addressed, including:
> * salient building codes, standards, as well as IEEE standards
> * roof aesthetic and programmatic criteria – weatherproofing, detailing, daylighting, glare control, skin condensation and acoustics
> * Natatorium block HVAC and electrical loads (post-Olympic)
> * structural design criteria and detailing
> * electrical production systems -- inverters, blocking diodes, DC wiring criteria
> * electrical protection requirements -- harmonics, maintenance and system protection
> * expected energy and power production
> * cost estimates of the implementation and construction of the photovoltaic system".

The findings of the feasibility study outlined several project guidelines from the anticipated production of the PV system to how to support a permanent roof for the system. The system itself was estimated to cost $5.1 to $6.4 million with the addition of $2.3 to $3.5 million to integrate the system into a permanent roof for the structure. It was determined that the proposed system should produce 569 MWh of energy and 336 kW of power. The electrical load for GTAC was sized for a 2000 kVA transformer. The optimum tilt for the modules to obtain maximum insolation was calculated to be eight degrees (±17°). It was also noted that a ten degree tilt was preferable for rain shed. The inverter, which determines the quality of the power produced, was identified as the most important and most expensive component of the system. The proposed PV system was classified by GPC Bulletin 51 outlining the requirements for the inverter.

In designing the roof structure, several design features were identified. The roof was required to: (1) be opaque; (2) be well insulated so that when GTAC was enclosed, there would be no steel corrosion; (3) be non-contributory to the bad acoustics inherent in natatoriums; (4) have weatherproof PV sealants since the sealants would be completely exposed on the roof; (5) be protected by lightning rods; and (6) have installed some device to service the PV panels. Two methods of structural support for the permanent roof were offered. Option 1 would employ bowed steel trusses at the east and west ends of the venue supported on each end by concrete-encased steel columns with a supporting steel tower in between. Option 2 would have much the same configuration, but instead of the trusses being supported on both ends, they would be cantilevered from the steel support tower. Finally, two methods of integrating the PV system with the roof were explored. Option 1 would construct the PV modules in a skylight system actually utilizing the modules as the roof cover. Option 2 would merely utilize the modules as skin that would stretch over a typical roof structure of insulation and vapor barrier. For more on these components as built, see section V. The feasibility study is incorporated in its entirety in Appendix C.

IV. THE PHOTOVOLTAIC MODULE SELECTION

There is an ever increasing number of companies which manufacture photovoltaic modules. Module technology can be categorized into three types: single crystalline, polycrystalline, and amorphous silicone. The processes by which the modules are created and manufactured vary greatly. The selection of the PV module plays a critical and driving force in the ultimate integration of PV into the facility. The cost of the module (usually quoted in watts) is yet only one factor to consider. The variables of the physical characteristics of the module will affect the construction cost in the areas of structural connections, electrical connections, thermal, and moisture protection systems.

Advanced Photovoltaic Systems (APS) was the amorphous silicone module supplier who initiated the Olympic photovoltaic project with Roger Preston + Partners. However, in April 1995, APS filed for bankruptcy. Thus, a new module supplier had to be found. The process which was developed for the PV module selection for GTAC was to issue a Request For Qualifications (RFQ). For this particular project, the timeline for delivery of the modules steered the selection committee toward 12 module manufacturers. Even though there are a large number of module companies, most have small production capabilities and could not meet a demand schedule for 340 kW of modules within the project schedule. Also the preference of a United States company was desired by the cost sharing partners: Georgia Tech, the US Department of Energy, and Georgia Power Company.

The RFQ focused on the two major areas of module data and company data. The module data indicates the stability of the module technology and physical characteristics which give one a sense of the integration design and cost. The company data indicates the financial strength, manufacturing capability, and experience with similar systems.

One weakness of many of the module suppliers was that they focused on module technology and production and were less experienced in actual systems design.

RFQ MODULE DATA:

- Technology
- Physical characteristics (i.e. weight, dimensions)
- Short-circuit current
- Open-circuit voltage
- Maximum power point current
- Maximum power point voltage
- Power output at NCOT
- Nominal cell operating temperature (NCOT)
- Coefficient for change in efficiency as a function of temperature
- Module efficiency at the maximum power point at STC
- Module stability as a function of time
- Module cost in dollars per peak watt ($/Wp) with or without frame
- Method of electrical termination
- Module UL certification

- Module mounting options
- Years of field experience with module

RFQ COMPANY DATA:

- Statement of corporate history, ownership, and structure
- Statement of corporate financial strength
- Detail provisions of manufacturer's warranty
- Factory capacity at normal operations annually
- Current/Future factory orders in kW
- Factory ability to deliver 340 kW of photovoltaic modules FOB to Atlanta, GA between October 2, 1995 and November 20, 1995
- Experience with similar scale projects in module delivery, system design, and system monitoring
- Performance bondability of company (minimum of $1,000,000)
- Legal actions brought against or being initiated by company in regard to contractability of company or delivery of modules
- Support of education in industry, private, and public sectors
- Support services (i.e. engineering of the system)

The selection committee collectively analyzed the RFQ. Each selection committee member then individually analyzed the RFQ's and reported their findings. A spreadsheet was developed for the committee's final evaluation and selection of a short list for interviews.

COMPANY	TECHNOLOGY	SCH & DEL	COST/WATT & MODULE WATTAGE	BOND 1 MILLION WARRANTY	% EFF.	ENG. SYSTEM EXP.
ASE*	multi-crystal	yes	$4.00-4.14/263	yes/10yr.	11.92	Low Converting from research to production
EPV (out, late submittal)						
United Solar*	amorphorus silicon	time frame Nov. 20	$4.50/22 watt panel	yes/NA	5.4	LOW 400 KW roof
Solec	single crystalline	June 20 order	$3.95/80 watt panel	yes/10yr.	10/14	N/A
Astrpower*	silicon crystal/ silicon film Spring 94 Pilot Plant	yes/2 technologies	$3.50-3.90-80/110 watt	NA/10 yr.	9.9/ 7.2	LOW-Sub contractor eng. sys.
Golden Photon/Mid 94 (risk)	CdTe	yes	$5.00/20 watt	yes/5 yr.	5.8	NONE
Siemens*	single crystal	yes	$3.70/48.6	yes/10 yr.	12.5	HIGH
Solarex*	multi-crystal	yes	$3.70-3.90/120	yes/20 yr.	10.9	HIGH
* Indicates Round 2 candidate						

It is important to note that the selection committee was comprised of various disciplined professionals for an unbiased opinion which related directly to the expertise of each member. In this project the following comprised the selection committee:

- Georgia Institute of Technology:

Richard Long	Architect, Office of Facilities; Principal Investigator
Ajeet Rohatgi	School of Electrical and Computer Engineering
Miroslav Begovic	School of Electrical and Computer Engineering

- United States Department of Energy:

Jim Rannels	Director of Photovoltaics Technical Division
Bob Martin	Photovoltaic Applications and Market Development

- Georgia Power Company:

Chuck Huling	External Affairs Power Delivery
Andy Hidle	Commercial Markets Division

- Post Olympic Aquatic Center Architect:
  - Rosser
- Photovoltaic Integrator Architect/Engineers:
  - Roger Preston + Partners
- Aquatic Center Design/Build Contractor:
  - Gaston-Thacker/Whiting-Turner
- Data Acquisition Consultant:
  - Southwest Technology Development Institute

The selection committee conducted interviews of four candidates for the module supplier. Each candidate was afforded 60 minutes for discussion. Fifteen days prior to the interviews, candidates were provided the site plan, roof plan, floor plans, elevations, and building sections of the facility. The candidates were requested to represent their module manufacturing and photovoltaic system capabilities, philosophies, examples of completed works, and experience in similar projects.

From the interviews, the selection committee ranked the candidates from number one to number four and instructed the Construction Manager to negotiate with candidate number one for the procurement of the modules. Once the negotiations with the selected module supplier, Solarex, were completed, the photovoltaic system design and integration could be completed.

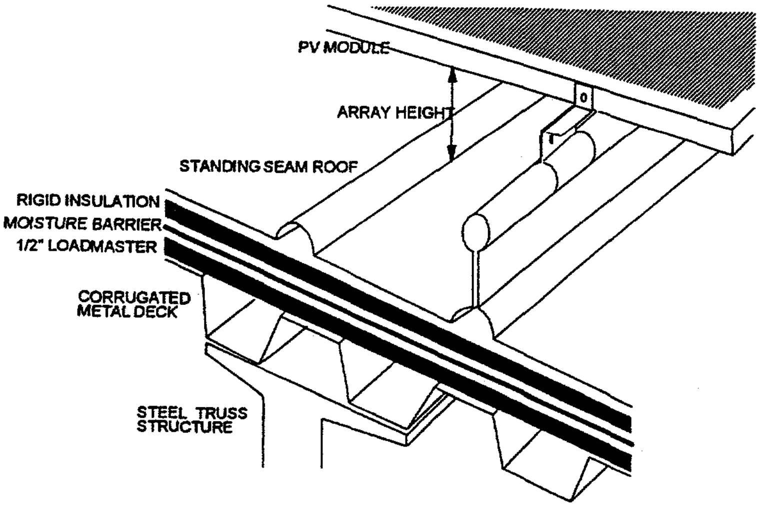
Design Considerations

Building integrated photovoltaic prototypes have advanced in the past several years in curtain wall design in vertical, sloped, stepped, sawtooth, and hybrid awnings applications. The facility is designed as an open air facility with a roof covering and is conceived to be enclosed after the 1996 Olympic games.

As the roof of the facility is approximately 65,000 gross square feet, it represented the ideal location for the photovoltaic power array. The design challenge was to incorporate the PV power system onto and into the roof system. The power system had to be designed with the lowest base operating cost commensurate with a minimum 20 year life span under the environmental conditions of the site.

Proper siting of the facility plays a critical role in the output of the power system which is directly proportional to the energy cost savings. The actual physical characteristics of the PV module play a critical role in the integration of PV in architecture. The color, size, weight, strength, and compatibility with conventional construction assemblies set the parameters for the system design. The module life, operation, safety and environmental considerations carry the initiative to justify the capital outlay to the system owners. It is not enough to have sustainable technology without sustainable/cost effective design.

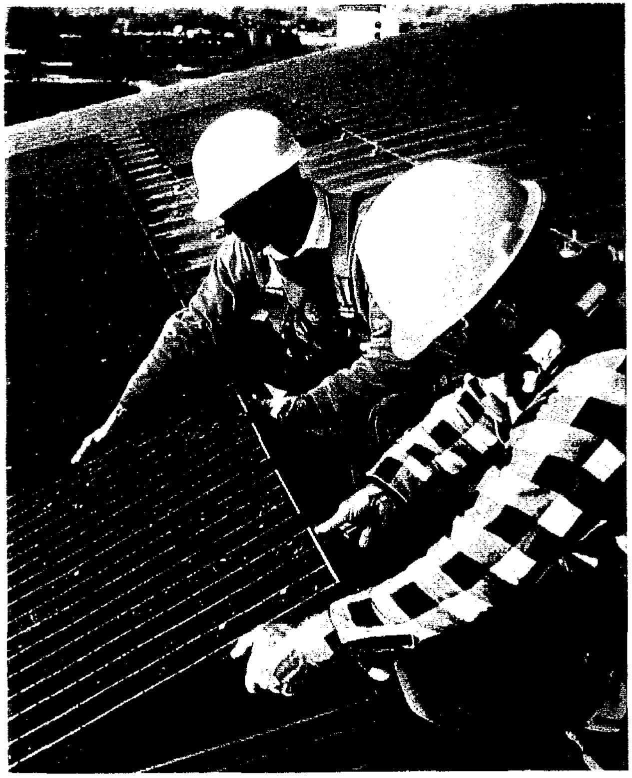
As the entire roof could have been a photovoltaic skin, funding parameters limited the PV array to 341 kW which equates to 49,471 gross square feet of roof area. Because the funding for the PV roof had not been solidified and pre-Olympic events in the summer of 1995 required a weather protective roof, a temporary metal roof deck with a 1/2" densdeck and EPDM membrane were specified. However, Georgia Tech desired to substitute loadmaster board and Grace Ice & Water shield for the specified roof components so that the transition could easily be made from temporary to permanent roof to support the PV array. The roof then became a barrel vault with a metal decking base welded to steel purlins and trusses, the Grace Ice & Water shield as a vapor barrier, loadmaster board, polyisocyanurate rigid insulation, and a standing steam aluminum skin.



Schematic representation of the array mounting scheme

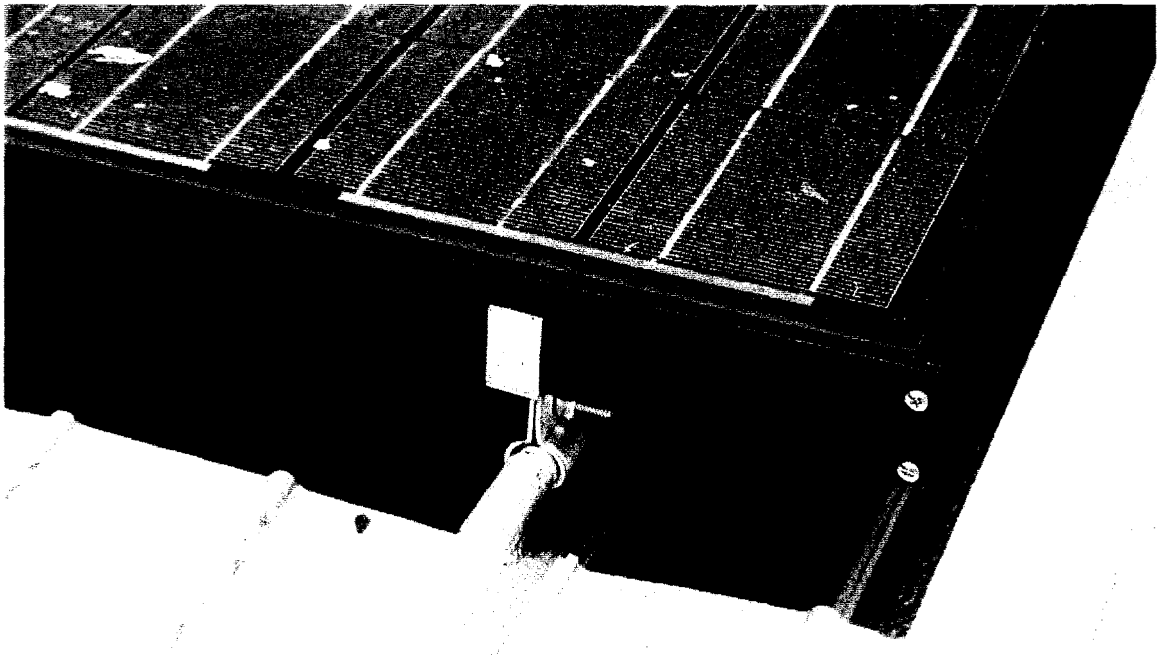
The design team evaluated two options to integrate the PV modules. One option evaluated the use of the PV panels incorporated into a standard curtain wall or skylight system. This system, while a valid system, proved to be less economical due to the fact that the metal deck and membrane would already be constructed. However, this curtain wall system was used in the construction of the SAC canopy mockup (see Appendix B).

The second option was to mount the modules to the already installed metal deck and membrane. The major concern was the amount of penetrations in the membrane to structurally attach the panels which could negate the integrity of the waterproof roof membrane.

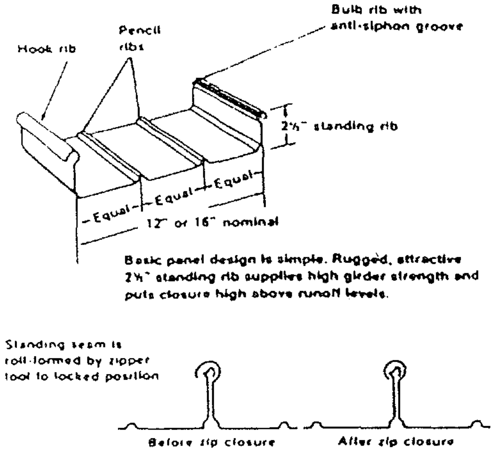


Given the concerns of the membrane and estimating the cost to structurally connect the panels, we began to look at various module mounting options which would protect the waterproof membrane. It became evident in the design process that a standing seam metal roof would accommodate both the structural connection of the PV modules without compromising the integrity of the waterproof membrane with structural mounting penetrations.

The standard photovoltaic module is manufactured with an aluminum frame. This frame then could be mounted to the raised rib of the standing seam roof via a stainless steel clip which is pressure mounted on the rib via a nut/bolt connection. This type of connection to the standing seam rib is an industry standard connection thus bringing the integration closer to architectural and construction standards.



PV MODULE ATTACHMENT TO STANDING SEAM

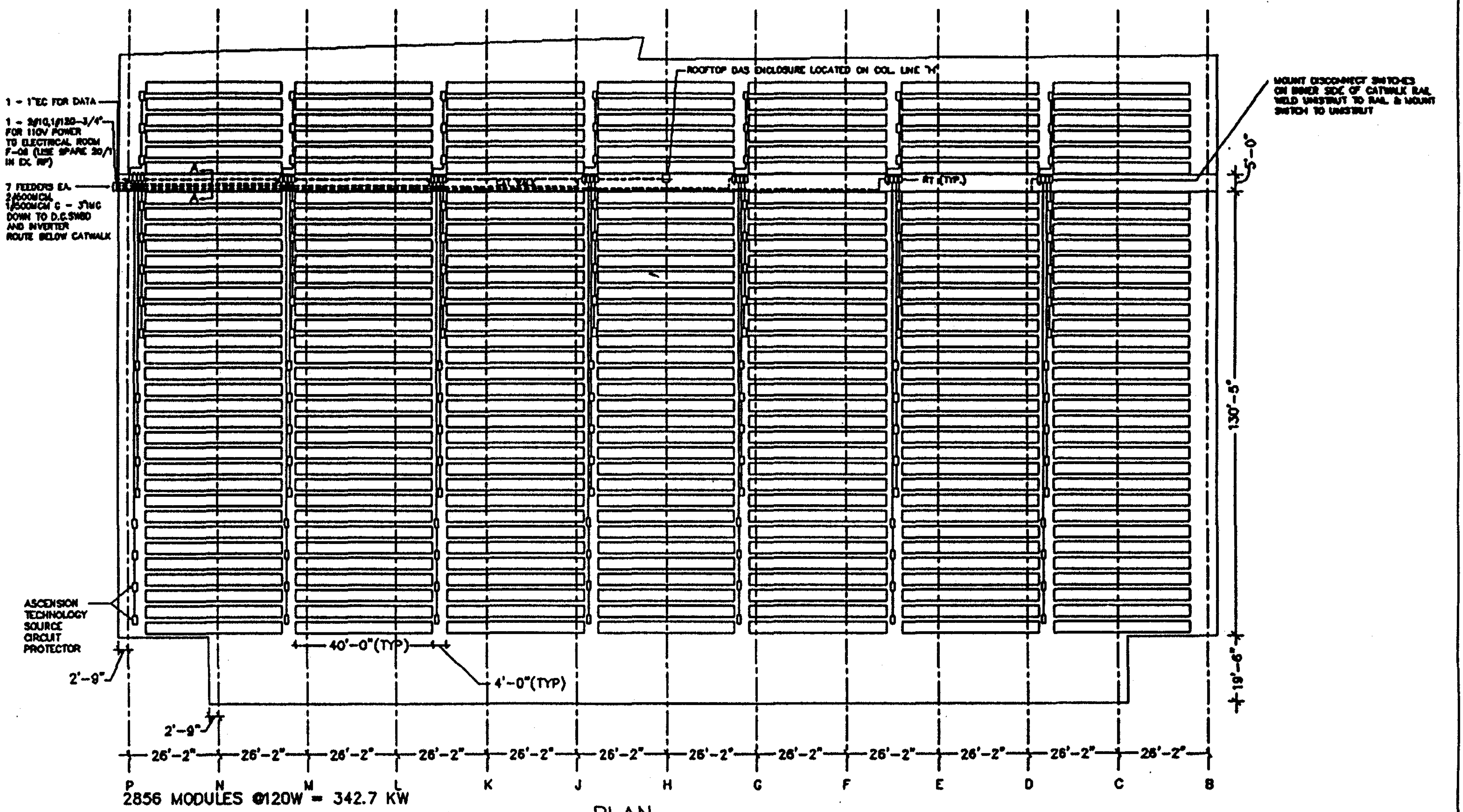


Basic panel design is simple. Rugged, attractive 2½" standing rib supplies high girder strength and puts closure high above runoff levels.

Standing seam is roll-formed by zipper tool to locked position

STANDING SEAM
PROFILE AND RIB CLOSURE

PHOTOVOLTAIC ARRAY PLANS



PLAN

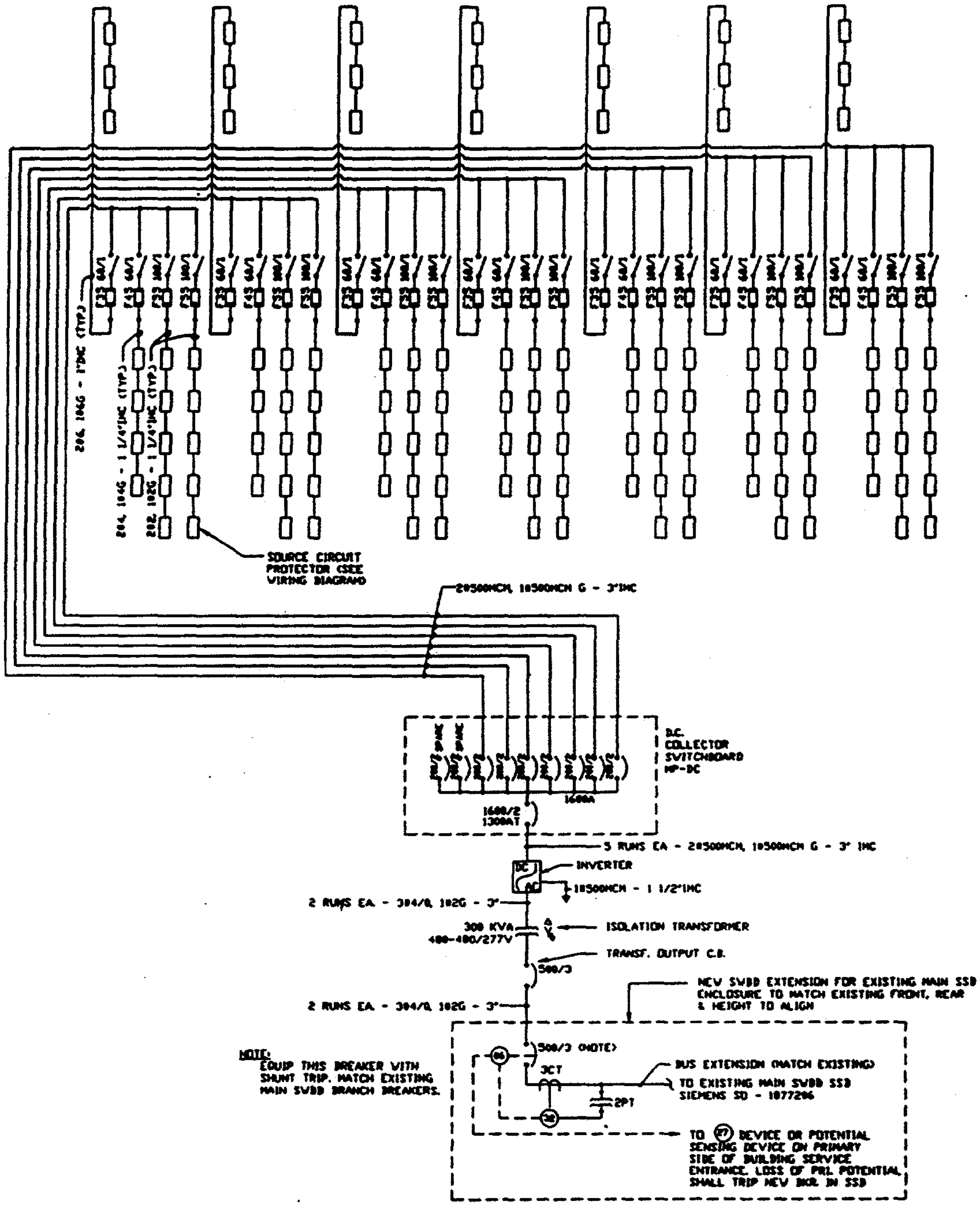
P.V. ARRAY ON ROOF

SCALE: 1/16" = 1' - 0"

PV ARRAY
CONFIGURATION

JOB NUMBER: 94407.02

E-2



SINGLE LINE DIAGRAM

PHOTOVOLTAIC COLLECTION SYSTEM

NO SCALE

NOTES:
1. REFER TO ARRAY PLAN FOR PHYSICAL CONFIGURATION.
2. SWITCHBOARD SHALL BE SIEMENS WITH TAPE WRAPPED COPPER BUS USING SENTRON JD6 AND PD6 BKRS.
3. FUSED SWITCHES SHALL BE SIEMENS MILL DUTY, TYPE 3R, 600V D.C., 3 POLE, F 352N W/GLK-4 LUG FOR 60 AMP AND F 353N W/GLK-4 LUG FOR 100 AMP - REFER TO SWITCH WIRING DIAGRAM.
4. PROVIDE AN ENGRAVED LAMICOID NAMEPLATE ATTACHED WITH S.S. SCREWS FOR EACH SWITCH NOTING "WARNING - BOTH SOURCE AND LOAD SIDE OF SWITCH IS ENERGIZED WHEN OPEN. SEE S.L.D."
5. FUSES SHALL BE BUSS FWP SERIES WITH ADAPTERS FOR DISC. SWITCHES.
6. ALL CONDUCTORS SHALL BE RATED 90°C, TYPE RHH/THHN.

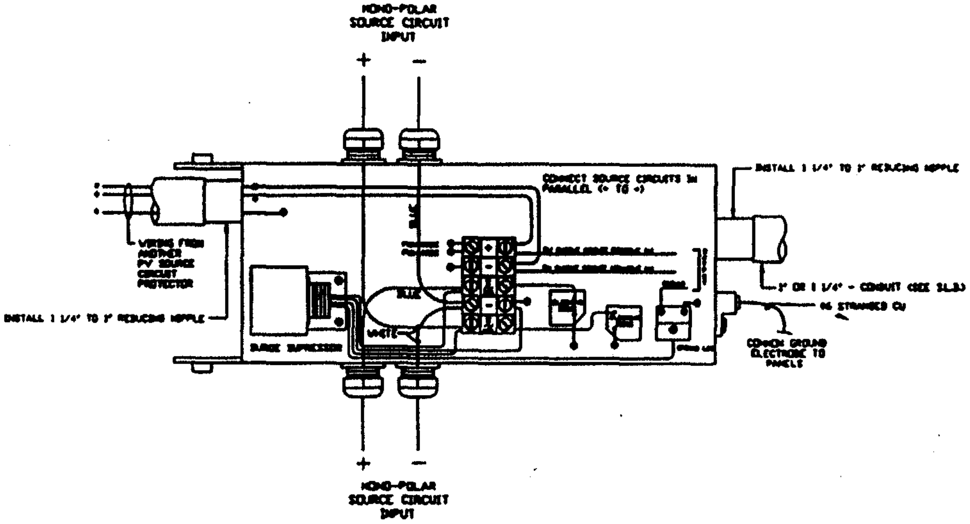
JOB NUMBER 94407.02

E-1

SINGLE LINE DIAGRAM

DRAWN BY:
DATE:
APPROVED:

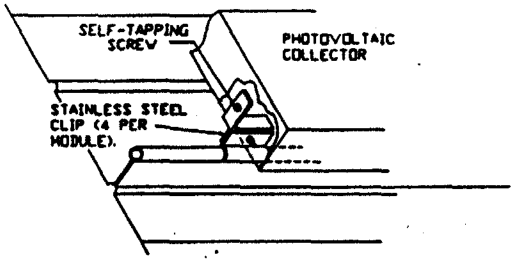
REVISION:



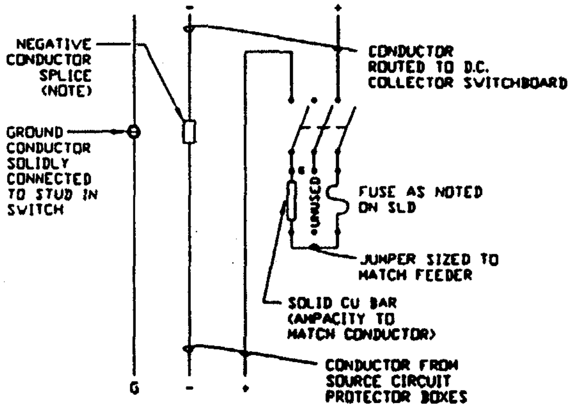
WIRING DIAGRAM

SOURCE CKT PROTECTOR

NO SCALE



STANDING SEAM ALUMINUM ROOF



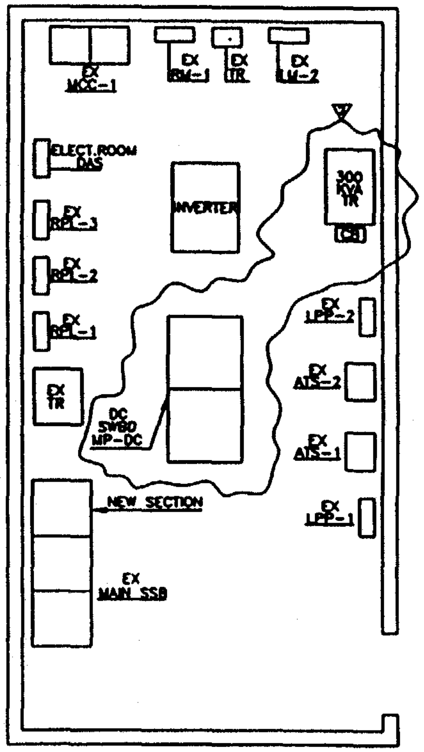
WIRING DIAGRAM

TYPICAL FOR 60/1 AND 100/1

ROOFTOP DISCONNECT SWITCHES

NO SCALE

NOTE: PROVIDE TERMINAL BLOCK TYPE CONNECTION.



EQUIPMENT LOCATION PLAN

SWITCHGEAR ROOM

SCALE: 1/4"=1'-0"

DRAWN BY: [illegible]
DATE: [illegible]
APPROVED: [illegible]

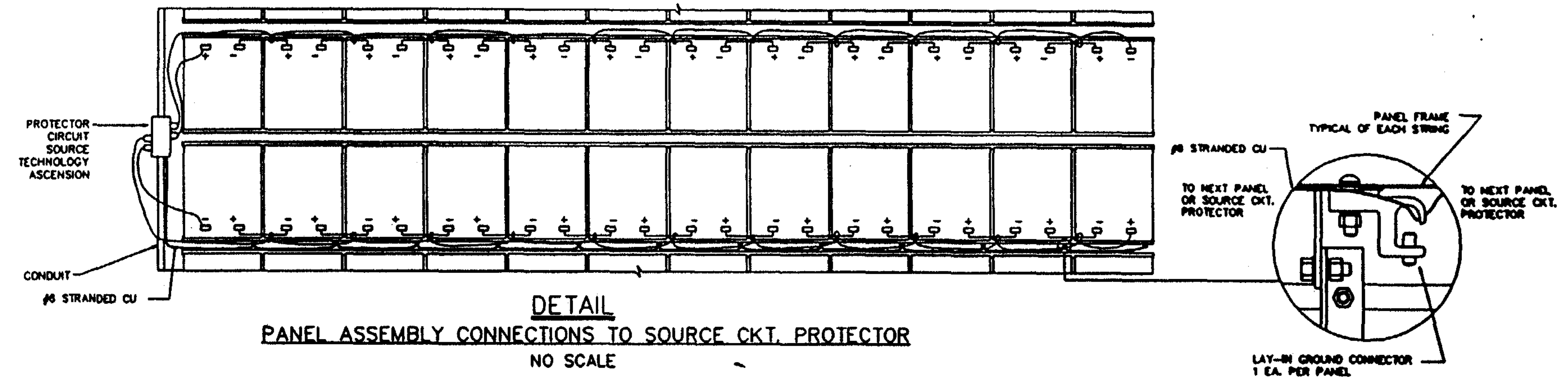
REVISION:
△ 11/[illegible]
△ 11/[illegible]
△ [illegible]

DETAILS
EQUIPMENT LOCATION PLAN

JOB NUMBER 94407.02

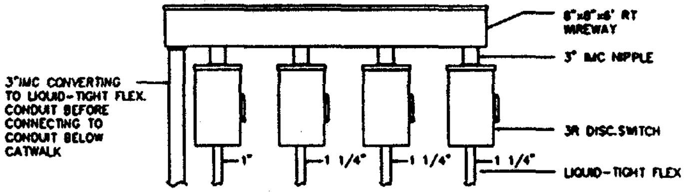
E-1

PHOTOVOLTAIC ARRAY PLANS



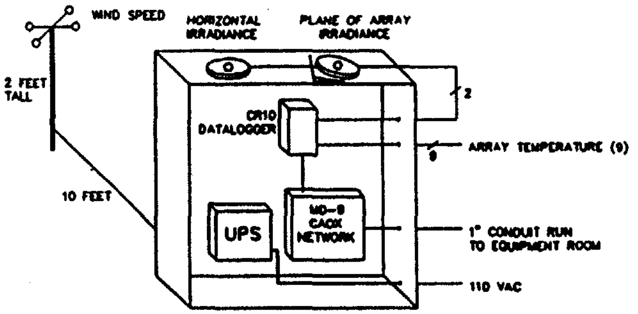
DETAIL
PANEL ASSEMBLY CONNECTIONS TO SOURCE CKT. PROTECTOR

NO SCALE



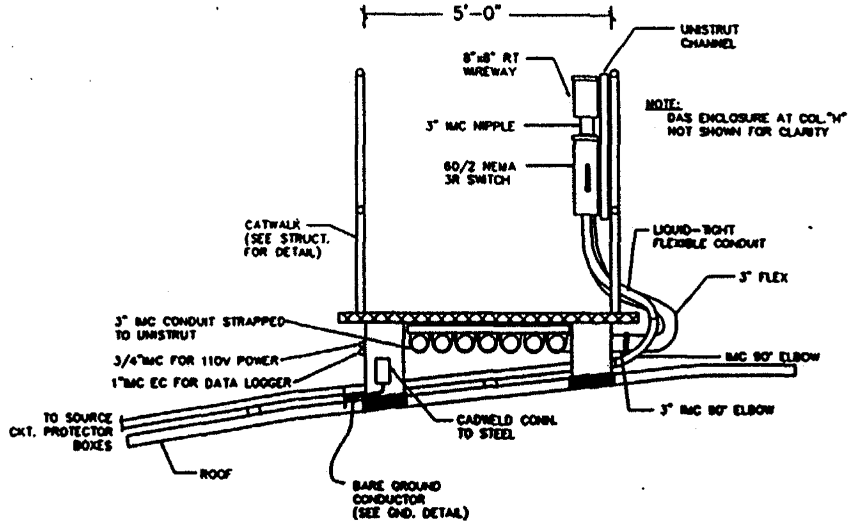
PARTIAL ELEVATION
TYPICAL SWITCH ARRANGEMENT

NO SCALE



DETAIL
ROOFTOP DAS ENCLOSURE AND EQUIPMENT

NO SCALE



SECTION A-A
CATWALK & CONDUIT

NO SCALE

DRAWN BY: [illegible]
DATE: [illegible]
APPROVED: [illegible]

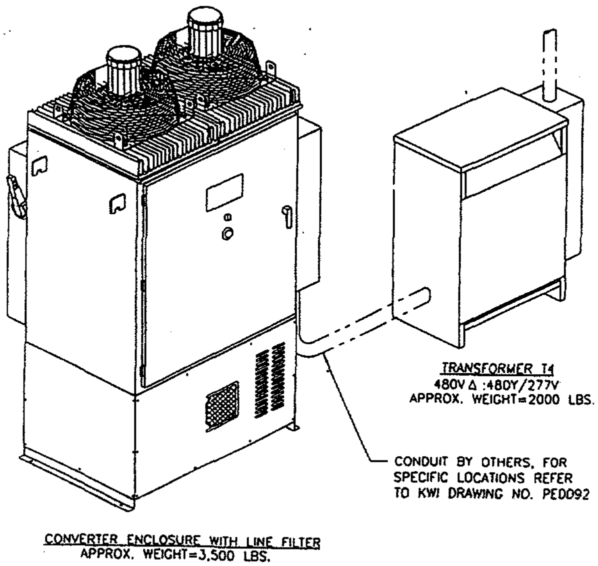
DETAILS

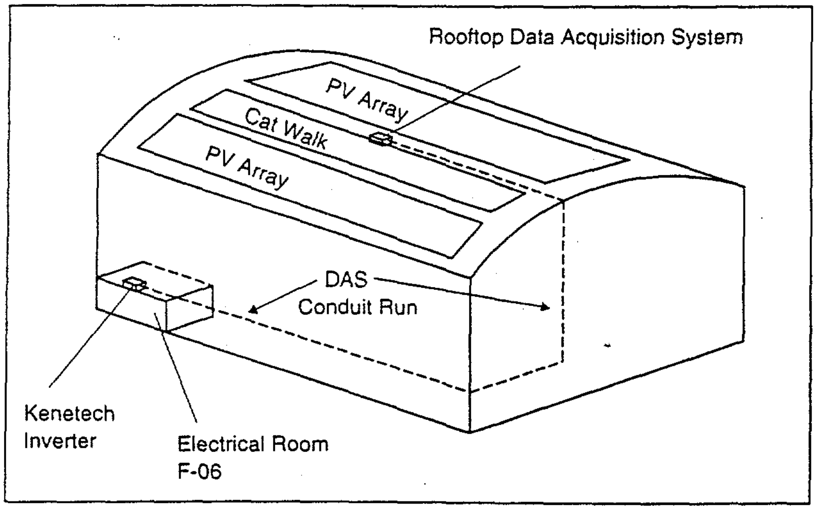
JOB NUMBER: 94407.02

E-2

Inverter

The power generated by the modules is direct current (DC) and requires conversion of the current to alternating current (AC) prior to being connected into the electrical main switch gear of the Aquatic Center. The inverter has the requirements of a short circuit of 400 volts or less, thus dictating the number of modules which could be in a string. The photovoltaic nomenclature is that cells make modules, modules make panels, panels make strings, strings make the array. GTAC employs 2,832 modules (each module containing 70 cells), 12 modules per string, and 236 strings. The inverter is located in the GTAC main electrical room adjacent to the main switch gear. The inverter for the project given line and efficiency losses was sized at 300 kW. The specifications for the inverter are attached in Appendix D.





System Configuration

Data Acquisition System (DAS)

As Georgia Tech is a center for excellence in PV design and research, the desire was to monitor the PV array for acquisition of information which could be used by the students and faculty for research and education.

The system is a meteorological and PV system Data Acquisition System that collects, stores, and distributes the performance data and supports interpretive display computers.

The long-term performance evaluation parameters consist of the following:

Meteorological Information

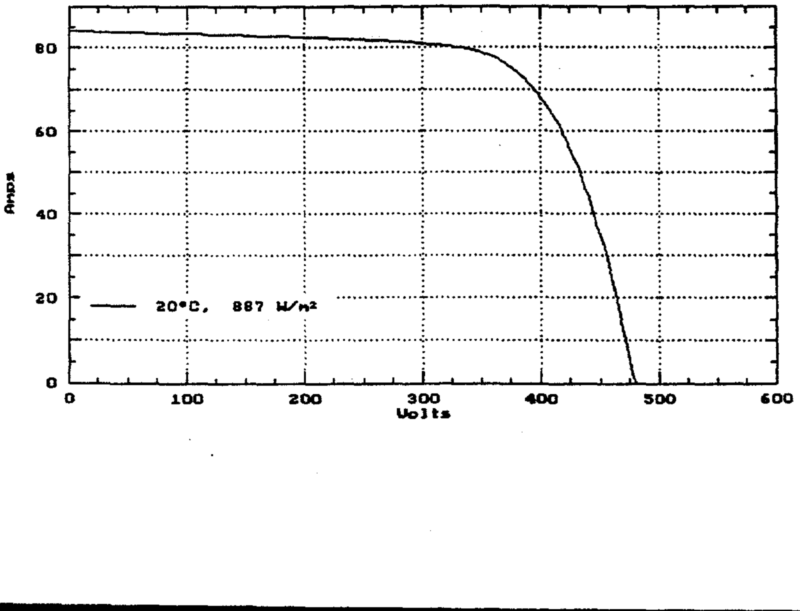
- Average Daily Maximum Ambient Temperature (°C)
- Average Daily Minimum Ambient Temperature (°C)
- Average Ambient Temperature (°C)
- Average Wind Speed (m/sec)
- Average Daily Horizontal Insolation (kWh/m^2)

Array Characteristics

- Array Area - m^2
- Tilt Angle 0 (degrees from horizontal)
- Azimuth Angle -
- Rated Array Power - kW

```
Site: ATLANTA          System:                     Name: B567
Date: 03-15-97         Module: B567                Misc:
Time: 11:19:26

Irradiance(W/m2)   887.0    Peak Power(Watts) 28369.5
Cell temp(°C)       20.0    I at Peak(Amps)      75.6
Isc(Amps)           84.0    V at Peak(Volts)    375.1
Voc(Volts)         480.5    Fill Factor(%)       70.3
```

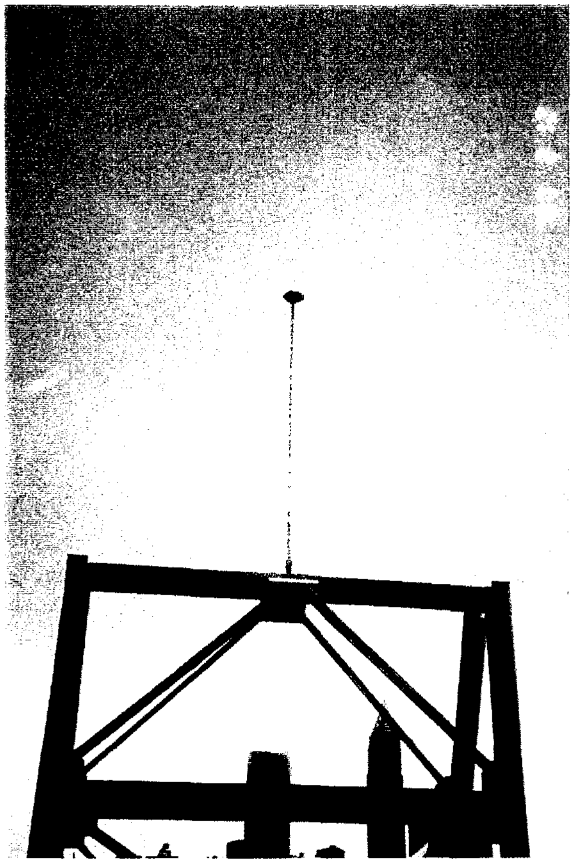


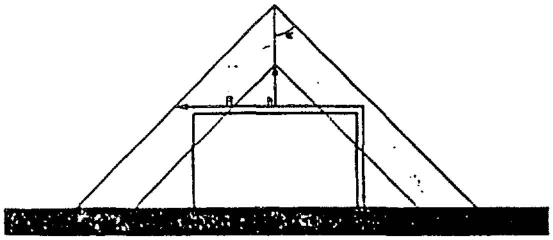
Computer Kiosks

In order to make the information collected by the Data Acquisition System available to the wide audience of Olympic participants in a user-friendly format, two touch screen kiosks were installed on site during the Olympics.

Lightning Protection System

The lightning protection system, the Preventor 2005 by Lightning Preventor of America, is designed to give lightning a safe path of travel to the ground. Lightning protection was crucial to GTAC where there was so much invested and completely exposed on the roof. The "Early Streamer Emission" system for this product generates ions during storms of opposite charge of the sky so that the greatest potential is created between the electrical device and the sky rather than the building and the sky. Thus, lightning is attracted to the ionizing devices and carried safely to the ground via 3/4" copper rod rather than hitting the PV modules. This system creates a cone of protection radiating from the ionizing air terminal. The required total protection radius was 328 feet in order to encompass 220 foot roof length. Two ionizing air terminals exist at either end of the 220 foot roof. The system has worked well in practice except for a malfunction of the system in the summer of 1996 which allowed lightning to strike and disable 11 modules.





LIGHTNING PROTECTION SYSTEM PROTECTION RADIUS DIAGRAM

VI. PROJECT COST

PV System Cost Summary

DESIGN/BUILD CONTRACT

CSI Division	Contract Amount	Itemized Scheduled Cost	Scheduled Cost	Amount Paid
General Conditions			$227,345	$226,298
CM Fee			$155,433	$150,546
Design Cost & Fees			$228,957	$223,005
Roger Preston + Partners		$118,000		
Rosser International		$109,957		
Contingency			$1,765	$0
Roofing Systems			$634,311	$644,311
Temp Roof Upgrades		$25,484		
Photovoltaic Systems			$1,577,026	$1,589,096
PV Panels Purchase		$1,286,722		
Install Panels		$105,350		
Inverter Purchase		$92,212		
Kennetech Startup		$9,503		
PV Canopy Mockup (see Appendix B)			$79,281	$79,281
Structures			$48,790	$48,790
Electrical			$358,704	$365,514
Lightning Protection		$13,000		
Finishes			$333,995	$331,505
SUBTOTAL	$3,604,000		$3,645,607	$3,658,346

CHANGE ORDERS

#	Description	Original Contract Cost	Funding Source	Scheduled Cost	Amount Paid
1	Masonry Enclosure		GT	$46,212	$46,046
2	Solar Thermal System (App. A)		DOE	$134,656	$138,744
3	Solar Thermal System (App. A)		DOE	$20,317	$20,317
4	Steam Heat Exchangers		GT	$89,800	$68,803
5	Kiosk System		DOE/GPC	$6,200	$5,809
SUBTOTAL (Change Orders #1-5)		$338,792		$297,185	$279,719
6	Outdoor Pool Bubble Enclosure (Post Olympic)		GT	$120,000	
Subtotal Change Orders #1-6				$417,185	
TOTAL		***$3,942,792***		***$3,942,792***	***$3,938,065***

Contract Amount less *Amount Paid* to date = $4,727.00

Permanent Roof Upgrade Estimate

Construction Estimate	$	1,205,766
Design Services Fee	$	110,630
Contingency	$	120,577
Escalation	$	36,173
Construction Management/ General Conditions	$	96,461
TOTAL	$	***1,569,607***

Soft Cost Calculation

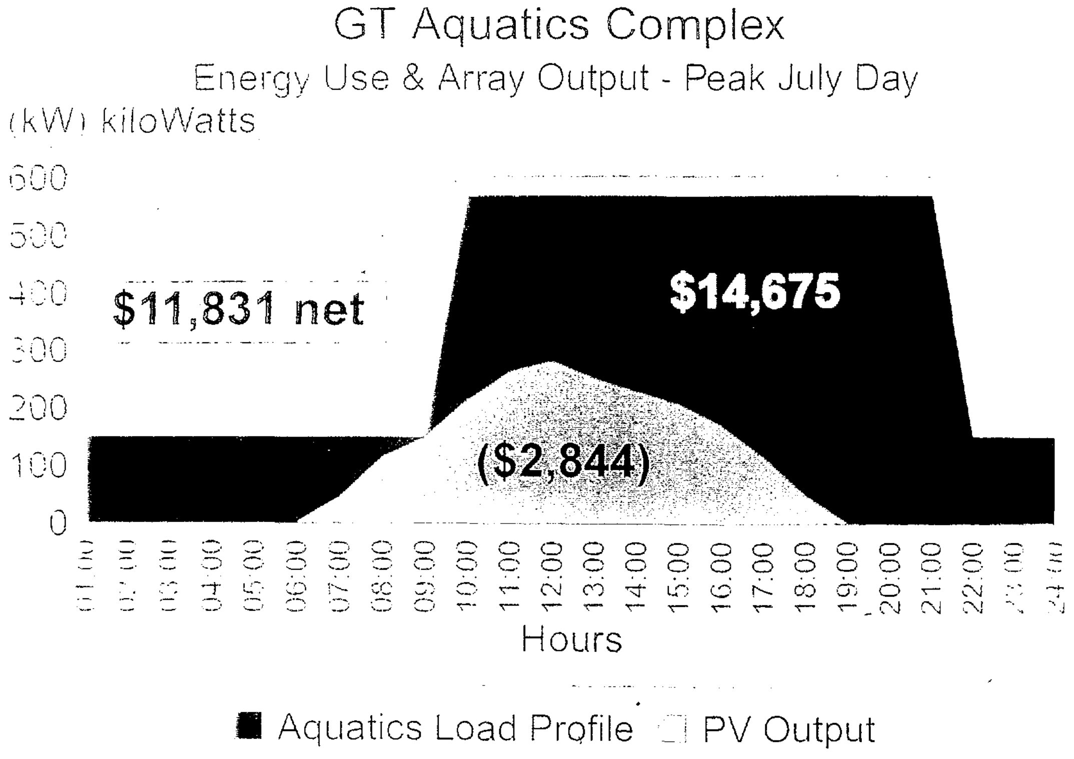
US Department of Energy Contract Sum	$	1,993,000
Georgia Power Company Contract Sum	$	1,848,000
SUBTOTAL	$	3,841,000
PV System Estimated Cost	$	-3,604,000
SOFT COST ALLOWANCE	$	***237,000***

Estimated Soft Cost Allocation

SERVICE	COMPANY		COST
Integration Studies/Canopy	Rosser-Fabrap	$	25,000
Feasibility Study	Roger Preston + Partners	$	42,000
Consulting	GT College of Electrical & Computer Engineering	$	66,000
Data Acquisition System	Southwest Technology Development Institute	$	30,000
Program Management	Draper Associates	$	25,000
Consulting	Programmed Media Environments	$	24,000
Contingency		$	25,000
TOTAL		$	***237,000***

Using meteorological data and technical specifications of the array, the photovoltaic power system will produce 424,600 kWh annually. The power system will provide approximately 42% of the facility's electrical load while it is open-air and approximately 25% when the facility is finally enclosed after the 1996 Summer Olympic Games.

This renewable generation of electricity will save approximately $30,000 annually on the operative cost of the facility. Depending upon regional cost for a kilowatt hour of electricity, the electricity costs range from 6.14 cents/kWh to 9.70 cents/kWh. Thus the savings for the same size PV array will range from $31,190 to $47,870 regionally. And in specific, if one looks at a state to state cost of electrical generation, this array would produce a cost savings of $51,350 annually in California.



While this photovoltaic power array was the largest roof-mounted array in the world when constructed, the payback period is approximately 57 years. Although this may seem a lengthy payback period, it must be noted that Georgia Tech purchases electricity from Georgia Power Company in "real time pricing" and "time of use" procurement agreements. Thus Georgia Tech is not subject to peak demand rates and purchases electricity at a substantial reduction in cost in comparison to the typical commercial consumer. A typical commercial consumer could (with proper demand management) have a payback period as low as 30 years. With proper maintenance, PV systems have a life span of well over 50 years. One must also take into account that there are intangible environmental benefits which one cannot quantify or qualify briefly within the context of this paper. Suffice it to say that the toxic emissions produced with the burning of fossil fuel or the by-product of nuclear electrical generation will be reduced by a considerable amount compounded over the life of the system. The more we integrate and construct renewable energy systems, the greater the impact on the environment and the greater the impact on the cost reduction of a photovoltaic array. By participating and promoting renewable energy systems we can help to restore the balance of the earth.

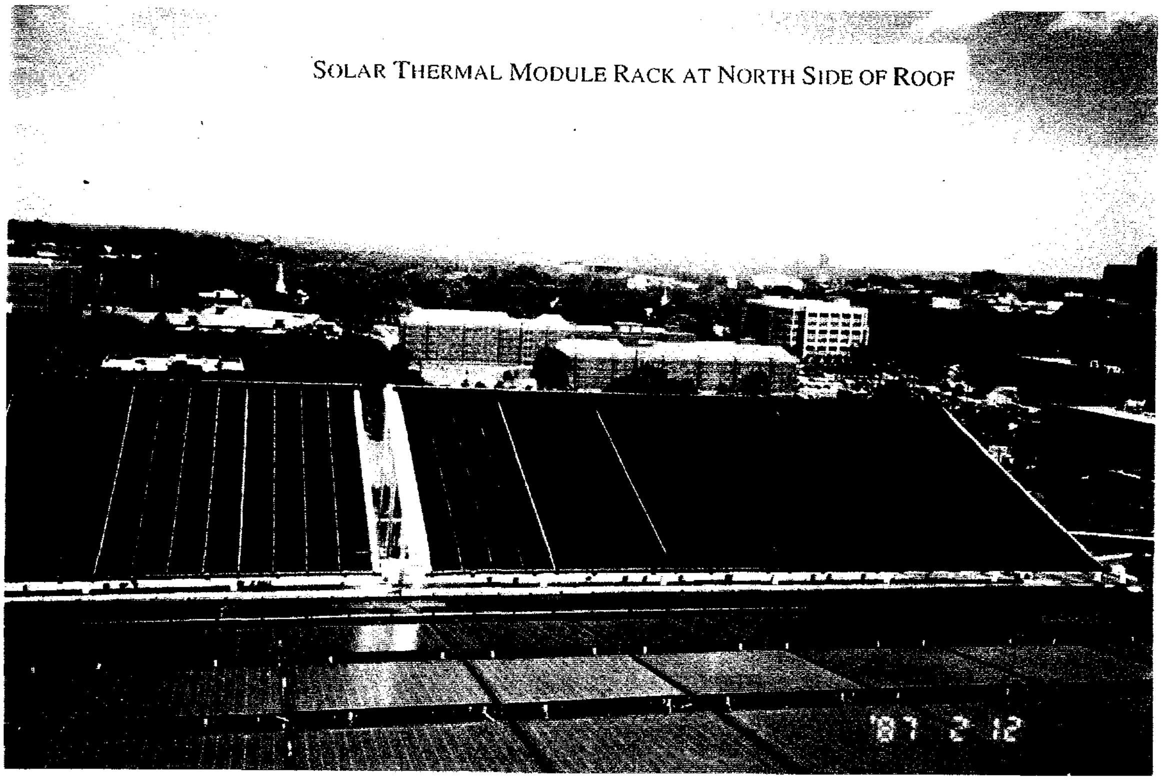
APPENDIX A
SOLAR THERMAL SYSTEM

In keeping with the desire to showcase renewable energies at GTAC, a solar thermal system was also installed on the Aquatic Center roof by Heliocol to directly heat the competition pool water. During Olympic competition, the water had to be maintained at 82 degrees + / - 1 degree. The 10,700 square foot system encompasses two sections of panels: one section 260' by 22' (63 collectors measuring 4'x18.5') mounted flush to the south edge of the roof and one section 319' by 29' (77 collectors measuring 4'x19.5') tilted at 20 degrees south on the north edge of the roof. It was necessary to tilt these north edge panels in order to maximize the collection of the sun's stronger southern rays. The open loop system has a 2,750 gallon capacity, processing 840 gallons per minute. A booster pump sends water from the surge tank up a 6" PVC feed line on the northwest corner of GTAC, runs the water through the collectors to gather heat, and returns to the surge tank via a 6" PVC return line. When not in use, the system is designed to allow the water in the system to drain back into the pool.

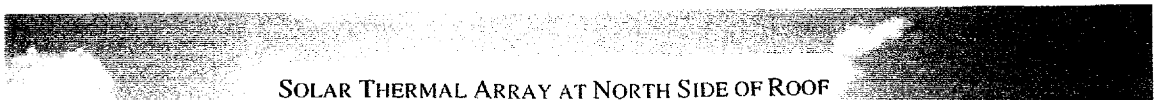
The system was entirely funded by the US Department of Energy including a feasibility study by Roger Preston + Partners (incorporated on the following pages). In this study, savings were estimated to be $15,000 with a payback period of 15 years.

Solar Thermal System Cost

Item	Estimated Cost		Amount Spent
Heliocol Proposal (labor & materials)	$ 121,800		
Value of Collectors Donated by Heliocol	$	$100,000	
Allowance for Electrical Design Review	$ 10,000		
Allowance for Structural Design Review	$ 5,000		
Electrical Work	$ 10,000		
Crane for Hoisting	$ 4,000		
Bonds & Insurance	$ 4,023		
Construction Management	$ 20,386		
TOTAL	$ 175,209		
US Department of Energy payments			
Change Order #2 (PV Contract)			$ 134,656
Change Order #3 (PV Contract)			$ 20,317
TOTAL			$ ***154,973***



Solar Thermal Module Rack at North Side of Roof



Solar Thermal Array at North Side of Roof

Report Issued:
August 9, 1994

An Evaluation of Solar Thermal Pool Water Heating Systems for the Georgia Institute of Technology Natatorium

August 1994

Prepared by:

Harris Sheinman, P.E.

Roger Preston + Partners
7000 Central Parkway
Suite 1470
Atlanta, Georgia 30328

Prepared for:

Mr. Richard Long
Georgia Institute of
Technology,
Facilities Department

ABSTRACT

The Institutional Conservation Program Division of the Department of Energy has funded this feasibility study of solar thermal pool water heating technologies at the Georgia Institute of Technology Natatorium during the Olympic Games. Issues specifically addressed in this study are: the solar potential of the site and collectors on the Natatorium's roof; the solar collection system's interface with the pools; an evaluation of the collectors' materials and compatibility; the efficiency of the collection system; estimates of the system's installed costs and energy cost savings; and a simple payback calculation of such a system as applied to the Natatorium. Thirteen solar collector manufacturers were interviewed. Hourly analyses were performed on the eight solar collectors. Cost estimates were performed using 1994 Means Mechanical Cost Data. Unglazed collectors were specifically analyzed, as they are much less expensive to install and as one manufacturer - Heliocol/SunStar - has offered to donate all of the collector materials required for the installation at the Georgia Institute of Technology Natatorium. Their collectors are fabricated of polypropylene, which has a fault: it can become brittle and break with UV radiation. We project that it will cost from $214,000 to as much as $277,000 to install a solar collection system for the Natatorium, ***exclusive of the collectors' material costs***. The solar collection system will produce as much as $15,600 net energy cost savings per year. Simple payback for such a system can be as little as 14 to 18 years.

TABLE OF CONTENTS

TABLE OF CHARTS

TABLE OF FIGURES

INTRODUCTION

HISTORY OF PROJECT

In the second quarter, 1994, the Department of Energy (DOE) and Georgia Power Company allocated moneys to construct a very large building-integrated photovoltaic array on the Georgia Institute of Technology's Natatorium, which will be used for the 1996 Summer Olympic Games. The DOE's participation in this project started from its *PV:Bonus* procurements and is to showcase the United States' alternative energy capabilities during the high-profile Games. Georgia Power's interest in the project illustrates the company's long-standing commitment to Demand Side Management. The Georgia Institute of Technology's interest developed from the research opportunities and status of such an advanced-technology project. Roger Preston + Partners (RP+P) will act as the system integrator, and Advanced Photovoltaic Systems (APS) will provide the photovoltaic materials for the project.

Since the award by the DOE's photovoltaic section, the Institutional Conservation Program Division of the Department of Energy's Energy Efficiency and Renewable Energy Group has indicated interest in showcasing its technologies during the Games as well. This feasibility study is the deliverable of the evaluation of the solar thermal heating of the pool water in the Natatorium.

DESCRIPTION OF NATATORIUM

The Georgia Institute of Technology (GIT) Natatorium will be a 64,400 square-foot (sf) enclosed competitive swimming and diving facility composed of: a 25m x 25 yd diving tank; a 25m x 50m swimming pool; pool decks; 4000 permanent seats; and ~28,000 sf of space for student use. The Natatorium will be set adjacent to the Colloway Student Athletic Center, in the place of the existing indoor pool (see figures 1 and 2, following). The Natatorium will be used, in various forms, for the swimming venues at the 1995 Pan Pacific Games, 1996 Olympic Games, and the 1996 Paralympic Games.

Figure 1-1: Rendering of Natatorium

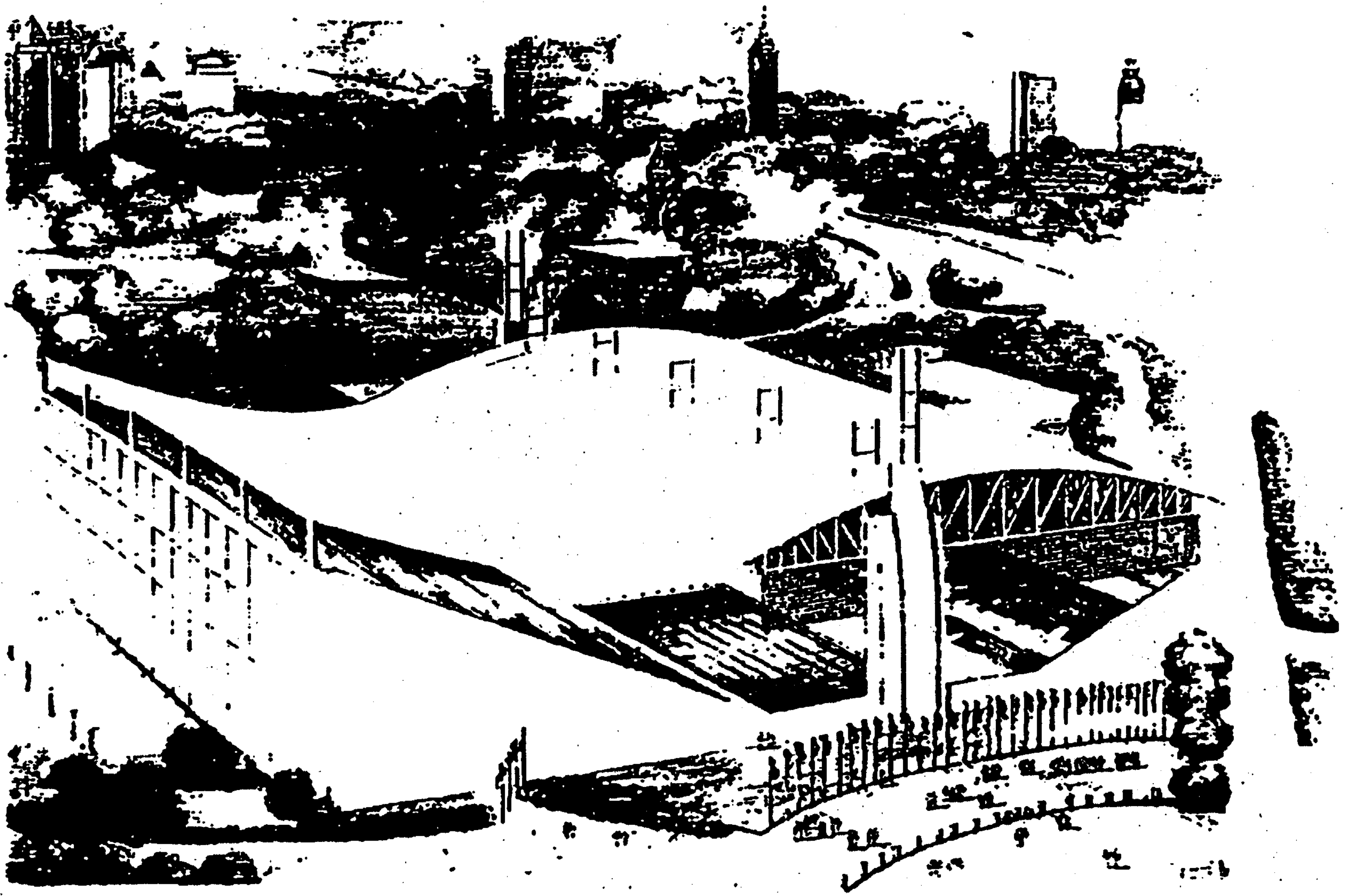
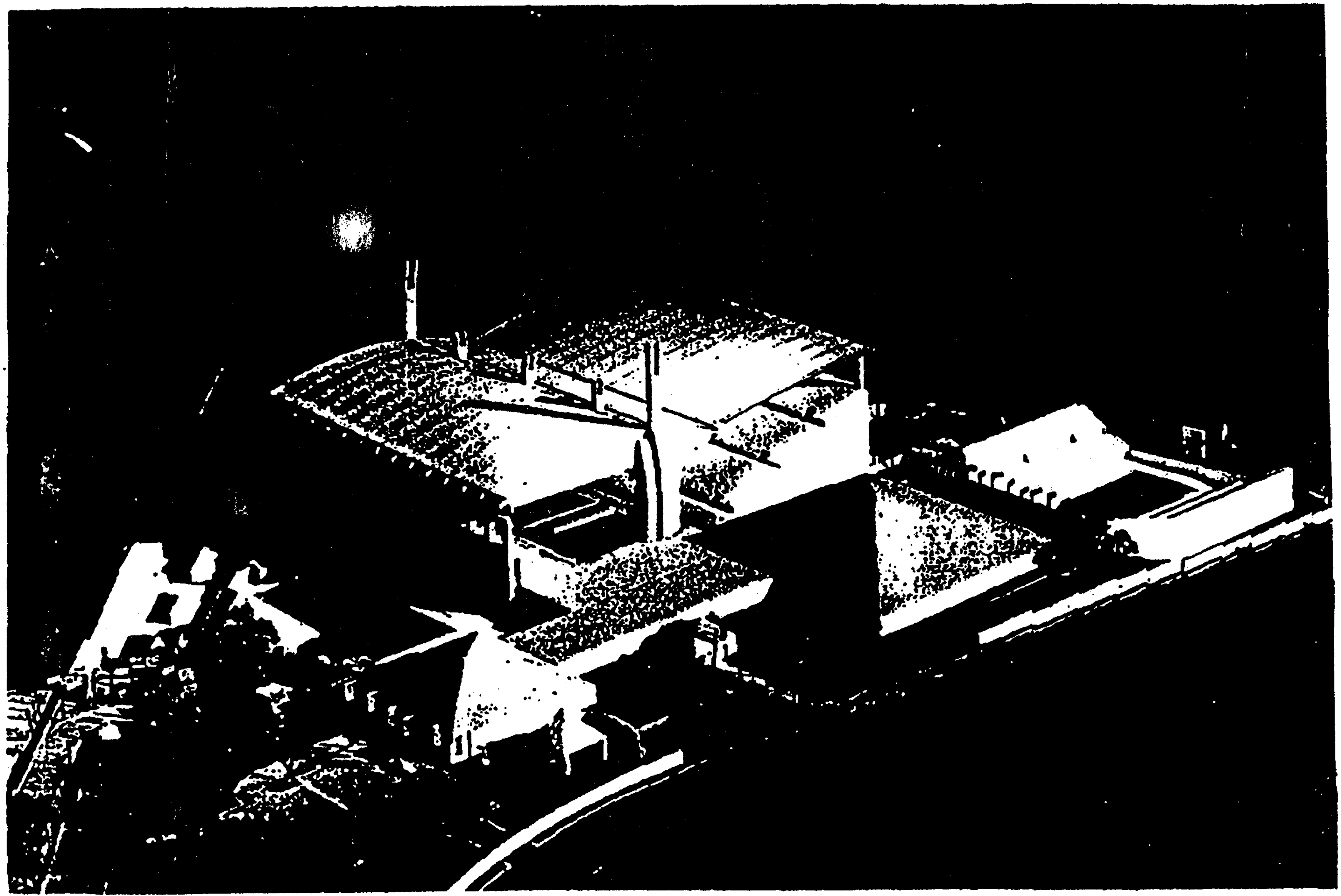


Figure 1-2: Site Model of Natatorium



Its construction and operation phases' descriptions follow:

Phase One, Initial Construction (May, 1994 through July, 1995):

- demolition of the existing indoor pool and site
- temporary enclosure of the existing outdoor pool for continued student use
- construction of the 25m x 25 yd diving tank, the 25m x 50m swimming pool; pool decks; 4000 permanent seats; and `28,000 sf of support space.
- construction of temporary covered decks and roofs for the Pan Pacific Games.
- this facility shall be used for the Pan Pacific Games in August, 1995.
- this facility shall also be used be Georgia Tech events through October, 1995.

Phase Two, Swimming Venue Preparation, for the Olympic Games (November, 1995 through June, 1996):

- add 11,000 temporary seats
- reconfigure 49,000 sf of the existing Callaway Student Athletic Center as support space
- provide 110,000 sf of temporary support space on site
- construction of the roof-integrated photovoltaic power conversion system.
- this facility shall be used for the Olympic Games in August, 1996, as well as the following Paralympic Games in September, 1996. From March, 1996 through June, 1996, as well as October, 1996, this facility shall house Georgia Tech competitive events.

Phase Three, Post Olympic Student Program (November, 1996 through life of facility):

- construction of the total enclosure of the diving tank, the competition pool, the pool decks, and the 4,000 permanent seats
- retrofit of the ~28,000 sf support space to student use space
- construction of the enclosed Natatorium's electrical and heating, ventilating and air-conditioning systems.

SCOPE OF REPORT

A professional services proposal sent to the Georgia Institute of Technology on April 20, 1994, included the following distinct tasks: a feasibility study for the solar thermal heating of the pool water, and an evaluation of the movable pool blanket opportunity. This report is the product of the solar thermal system's feasibility study. It is designed to assist The Department of Energy and the Georgia Institute of Technology in their decisions for these technologies' implementation. To that end, several project-specific issues are addressed, including:

- salient building codes and standards
- roof aesthetic and programmatic criteria -- weatherproofing, detailing, and uplift;
- Natatorium pool evaporation loads (while the pool is both enclosed and open to the weather);
- architectural and structural design implications;
- systemic criteria -- piping, pumping and protecting both the pool and the solar thermal system;
- expected energy production and conservation; and
- cost estimates of the implementation and construction of the solar thermal system

This report is decidedly pragmatic. While the report does list a literature search, it does *not* provide academic discussion of the physical construction of the selected solar thermal technologies, nor of the application of solar thermal technologies to various other building types or loads. The report does however list some of this [cited] information, for ease of evaluation.

SOLAR THERMAL POOL WATER HEATING TECHNOLOGIES

DESCRIPTION OF TECHNOLOGIES

This discussion does not address all of the various solar thermal heating systems, but rather only those which are designed for pool water heating use. The collectors serving pool water systems can be divided into two groups: unglazed flat-plate collectors, and glazed flat-plate collectors.

Unglazed collectors are ideal for low-grade heating applications - where the water temperature inside the collector is less than 40°F above the ambient air temperature[1]. The collectors' efficiencies are better than the glazed collectors at these temperatures, as they've no glazing transmittance deration, and their convective heat loss is small. The unglazed collectors are, save for one manufacturer[2], fabricated in tube sheets, bonded or molded to headers, all made of EPDM, polypropylene (with UV stabilizers), or a combination of the two.

The materials used in the unglazed collectors are cause for concern for the Natatorium: EPDM powders, and is responsible for many "black pools" throughout the country over the last two decades; polypropylene, even with stabilizers, becomes brittle under UV radiation, and has been responsible for many breaks in the collector tubes and headers. The combination of the two materials is really an polypropylene encapsulation of the EPDM material. The quality control of the encapsulation does not provide materials which are fully encapsulated, so there is still a risk for "black pool" occurring. Warranties do not seem very strong for these materials, but explicit warranty could be required as a point in the specification of the materials.

Glazed collectors are better for applications where the fluid temperatures in the collectors are higher. Their efficiencies are better at higher temperatures as the

---

[1] Typical for the pool-heating market.

[2] Techno Solis, which makes a true *mat*, with internal tubes

glazing provides a thermal break against the collectors' convective losses. these collectors are, save for one manufacturer[1], fabricated of copper or EPDM tubes and headers.

Some problems associated with these types of collectors are hot-spot development around the edges of the collectors (allowing for the collection of HCl gas if they are direct-connected to the pool water), material expansion/contraction mis-matches, and their high material and installation costs.

The unglazed collector manufacturers are more ready to donate materials to the Georgia Institute of Technology than the manufacturers of the glazed units. One manufacturer, Heliocol/SunStar, is quite enthusiastic about donating the material, provided that it is in place and operating by the Olympics. As such, the analyses in this study are targeted at the unglazed products, and specifically at Heliocol/SunStar. The analyses for the Heliocol/SunStar collector are applicable to the other unglazed manufacturers as well, as the differences are really only in material longevity and not the conversion efficiency.

The following table lists manufacturers of solar collectors, contact persons, fabrication materials, standard day performance, costs, and applicability to this Natatorium.

---

[1] Thermomex, which uses an evacuated tube/heat pipe technology, which seems most useful in cold climates.

Chart 2-1: Manufacturer Survey

Manufacturer	Contact	Technology/ Materials	Standard Day Performance	Cost	Comments	Applicability to this Project
American Solar Network, Ltd.	Al Rich, (916) 481-7200	Glazed with polycarbonate; EPDM matte absorber	783 btu/sf-day; SRCC 15000 btu/sfd insolation & 9°F	~$10.50/sf materials; $20-$60/sf total	ERIP Grant Winner (Elliot Levine of DOE is the project manager)	
Aquatherm Industries, Inc., (Solar Industries div.)	Richard Holstein, (800) 535-6307	Matte; black polypropylene tubes, w/webbing	935 btu/sf-day	~$2.75/sf materials	No FSEC data provided; no analysis performed	some mat'l can be donated
Bio-Energy Systems, Inc.	Brian O'Kane, (914) 647-6700	polypropylene or an EPDM material	805 btu/sf-day	unknown	No FSEC data provided; no analysis performed	
FAFCO	Jan Thurber, (415) 363-2690	COMPANY NOT INTERESTED IN PARTICIPATING				
Harter Industries	Don Harter, (908) 566-7055;	Matte; uses Santoprene, a Monsanto EPDM encapsulated with polypropylene product, to which is added some anti-oxidants.	823 btu/sf-day	~$2.75/sf materials		
Heliocol USA, Inc.	Victor Eyal, (407) 831-1941; fax: 407-831-1208	Matte; black polypropylene tubes preformed into headers	900 btu/sf-day	donated	Oldest in the US is 17 years	DONATED Unconditional warranty for 10 years
Heliodyne, Inc.	Jurg Bieri, (510) 237-9614	Glazed, copper tubes, black chrome backing; plate floats inside collector case 4'x8' or 10'x4" 155#	891 btuh/sf-day; SRCC 15000 btu/sfd insolation & 9°F	~$14.00/sf materials		Does Navy pools
Radco Products, Inc.	Mike Orloss, (805) 928-1881, (805) 772-8601	Glazed collector, with copper manifolds & tubes	1270 btu/sf-day	unknown		
SunEarth, Inc.	Rick Reed, (800) 778-5270;	Copper Plate collector with a glazed top	953 btu/sf-day	unknown		Not able to donate
The Art of Solar	Art Brooks (909) 483-2495	Matte collector, using an EPDM	979 btu/sf-day	~$2.50/sf materials	Can withstand about 225°F temperatures	

Chart 2-1: Manufacturer Survey

Manufacturer	Contact	Technology/ Materials	Standard Day Performance	Cost	Comments	Applicability to this Project
Thermal Conversion Technology	(813) 953-2177	COMPANY GAVE NO RESPONSE TO REQUEST FOR INFORMATION				
Thermomax USA, Ltd.	Dr. Mahjouri (410) 997-0778	Heat pipe (using p glycol as the refrigerant, collector plate coaxially bonded with a copper evaporator pipe, which is inside a glazed vacuum tube)	897 btu/sf-day	6.5'x2.75' tubes; each tube is $68/tube list price		
Techno-Solis, Inc.	Lou Cressia (813) 573-2881	Unglazed polypropylene flat plate collector, w/elliptical flow channels embedded in the 0.035" thick plate; can go up to 170°F & 30 psi; welded to EPDM headers; balanced flow thru "orifice plates" in tube/ header offsets.	958 btuh/sf-day	$2.00/sf material cost		

POOL WATER CONDITIONING SYSTEM INTERFACE

The typical residential solar pool collector application can be called a "draindown system," which is directly connected to the pool's filtration pumping system, and uses the pool itself as a sump. This system type is not appropriate for the Natatorium design, because of the risk of a "black pool" (from EPDM powdering and leaching into the pool water, see discussion above). Our system model includes isolation heat exchangers for an indirect connection between the solar collection system and the pool water. The heat exchangers de-rate (by raising the fluid-in temperature) the collectors' effectiveness by only 1.04%. The heat exchangers also may allow for a closed loop solar collection system, which could lower the solar system's required pump horsepower by one-half and provide a cheaper installation and a quicker payback. Our model does not include this closed-loop design, as such a design requires an anti-freeze to be mixed with the solar collection system's water, and the manufacturers interviewed were not certain of the materials' compatibility with a glycol brine. So, our model includes a drainback tank, for freeze protection.

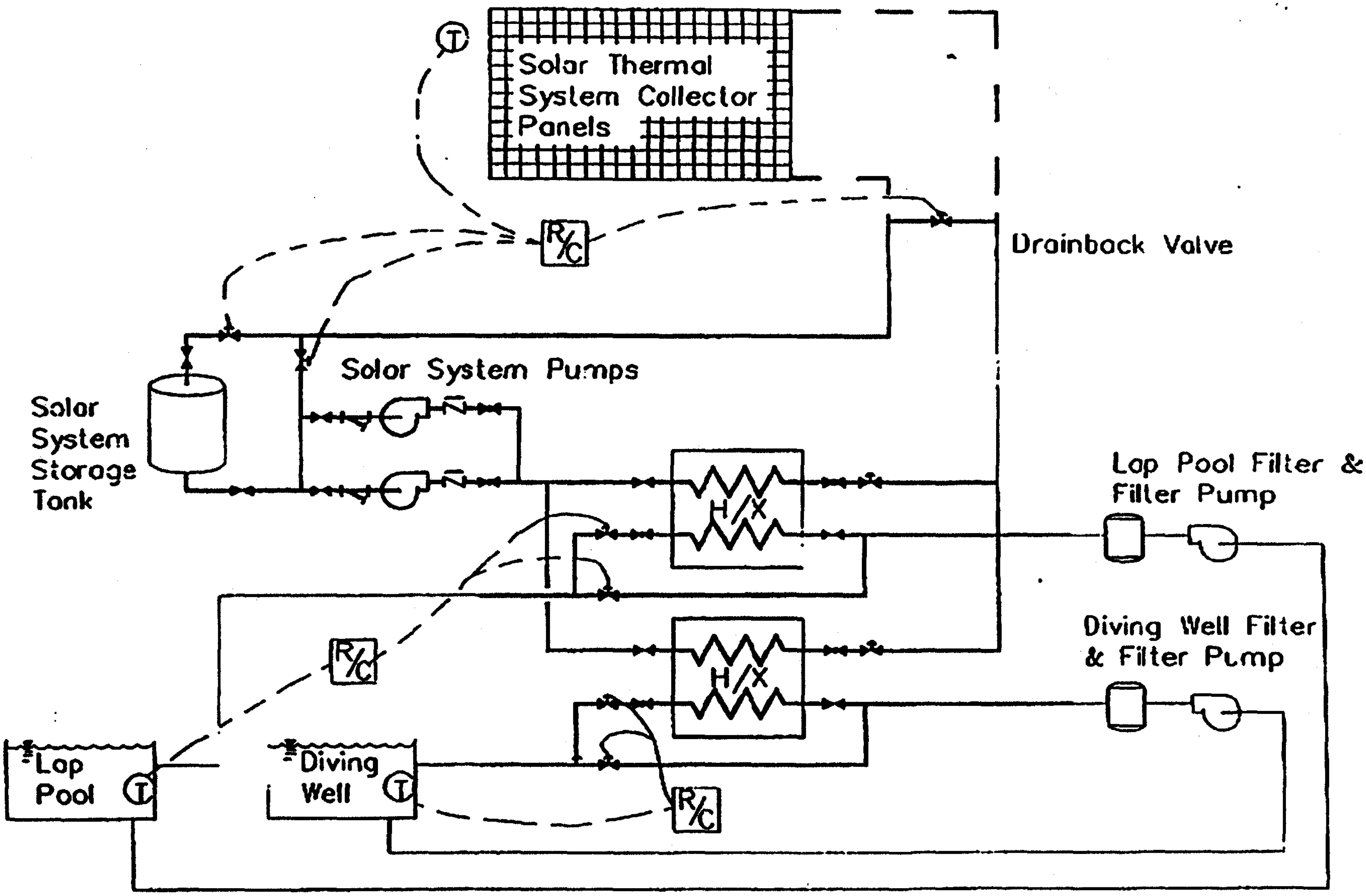
The model uses the pool water filtration pumps as the motive force for the pool water, as the flow rate is rather high[1]. Coordination of the pool filter pump heads with the additional heat exchanger pressure drop is required for the solar collection system is to be installed in the Natatorium.

Please see a schematic of the modeled solar collection system for the Natatorium, following.

---

[1] The collectors do not provide a large temperature difference.

Figure 2-1: Solar Thermal System Piping Schematic



DESIGN CONSTRAINTS AND IMPLICATIONS

The unglazed collectors are fabricated of black plastic, with tubes which are small. The collectors will lay flat on the roof, much as the photovoltaic array will. The solar thermal collectors will, like the photovoltaic array, provide a "slick" roof. They are extremely light: their weight, when loaded with water, is less than 4 psf. The connection of these collectors is likewise very simple, mostly through the use of pre-molded[1] mounting jigs screwed into the roof deck itself. These products were designed for installation by homeowners or light contractors. The collectors should be located on the extreme south end on the roof, where it is most sloped, for enhanced collection during the winter, the prevention of stagnation, and the provision of drainback for freeze protection.

---

[1] by the manufacturer

POTENTIAL COSTS AND ENERGY SAVINGS

The benefits of applying a solar collection system to the Natatorium were examined through detailed hourly energy conversion calculations for the modeled collection system, and these results were correlated with the pools' conditioning loads to determine an optimum selection. Those pool loads were established in a similar fashion, through hourly heat loss and heat gain calculations. The analyses are only performed on the enclosed Natatorium, to limit oversizing the collection system, and consequently, its payback. Both the solar collection system's energy conversion calculations and the pools' conditioning loads were performed using custom-written computer programs/spreadsheets using average hourly meteorological data for Atlanta.

APPLICATIONS ADDRESSED

This feasibility study explored of three applications for the solar thermal collectors: solar pool water heating; (solar) pool water cooling; and solar Natatorium air reheat (for humidity control). The last two applications are not included in this report, as we found that they've no application to this Natatorium.

Cooling the swimming pool water may be easily accomplished with non-glazed pad collectors. Little technology is required: a lawn sprinkler spraying water onto the collectors is all that is needed. The cooling process is similar to that of an evaporative pad cooler. This application seems to work best in the Southwest United States, where the ambient conditions are hot and dry. It could work in Atlanta as well, but the pool, covered by the roof, requires no cooling.

Reheating the enclosed Natatorium air for humidity control seemed to be another application, in the following configuration: pipe the pool water, after filtration, through a reheat coil in a face/bypass air handler, and then through the solar collection system's heat exchanger. This configuration lowers the entering fluid temperature into the collectors, and so allows for more hours for energy conversion at the collector face.

This application is not relevant, because the only time a face/bypass air handler would need reheat control is in the evening, after the sun has set.

The remainder of the report's analysis addresses the solar heating of the pool water, described below.

POOL USAGE SCHEDULES

Construction of the Natatorium is to be completed in three stages with two intermediate facility usages occurring between construction phases. The projected construction/usage schedule follows:

Present through July 1995	- Initial facility construction - pools and permanent seating
July 1995 - October 1995	- Open for Pan Pacific Games and Georgia Tech competitive events
November 1995 - March 1996	- Temporary construction for additional Olympic facilities - pools closed
April 1996 - October 1996	- Olympics and Georgia Tech competitive events
November 1996 - September 1997	- Construction of permanent Georgia Tech enclosure - pool closed
Beginning January 1998	- Normal Georgia Tech use

From this schedule, the pools will be used under a variety of conditions. During the summers of 1995 and 1996, the Olympic pools will be shaded by a roof structure and pool deck-to-roof seating along the long axis of the pools. Since the Olympic diving well and competitive pool are aligned along a common east-west center line, the seating will line the north and south sides of the pool. The east and west sides of the structure will be open. The outdoor pool will not be altered and will remain as an outdoor pool. During the Pan Pacific Games and the Olympics, all pools will be heated and cooled to maintain strict water temperature requirements. By the beginning of 1998, the Olympic pools will be totally enclosed and used year-round. Once construction is completed, the enclosed pools (Olympic diving well and competitive pool) will be available year-round. The outdoor pool is used only from April through October. Georgia Tech intends that all pools will be open from 6 am until 10 pm, seven days per week.

POOL ENERGY CONSUMPTION CALCULATION APPROACH

We modeled the energy required to maintain the pools and diving wells at the required water temperature using algorithms similar to those used by the RSPEC program. Our algorithms express the energy balance for the pool for each square foot of the water's surface. This balance can be expressed as:

$$q_{source} + q_{evap} + q_{conv} + q_{rad} + q_{solar} + q_{makeup} + q_{store} = 0$$

where:

q_{source} = source energy required to heat or cool the pool to the desired temperature,
q_{evap} = energy lost as a result of water evaporation,
q_{conv} = heat transfer resulting from convective effects,
q_{rad} = heat transfer resulting from radiative effects,
q_{solar} = heat gain resulting from the absorption of solar radiation,
q_{makeup} = heat gain or loss resulting from the addition of make-up water, and
q_{store} = heat stored in the pool if its temperature is allowed to rise above the setpoint.

We obtained the evaporation, convective, and radiative transfer from documentation of the RSPEC computer simulation program and additional publications, all provided by Randy Martin of the Denver regional Department of Energy office.

The energy lost as a result of evaporation is calculated as:

$$q_{evap} = A_f(68 + 32V_p)(P_w - P_s)$$

where:

A_f = activity factor, taken to be 1.0 for a quiet pool and 1.3 for normal use
V_p = wind speed over the surface of the pool in miles per hour, where

$$V_p = 0.15V_w,$$

where V_w is the weather station wind speed obtained from average weather data,
P_w = saturation pressure of water at the pool surface temperature in inches of mercury, and
P_s = saturation pressure of the water vapor in the air above the pool in inches of mercury.

Structures adjacent to the pool act as wind breaks, affecting the wind over the pool surface. When the Olympic pools are covered by a roof, but not enclosed at either end, seating along the major east-west axis of the pool blocks wind from the southeast to southwest and from the northeast to northwest directions. We lastly assume that, once enclosed, HVAC equipment will blow air at a 25 feet per minute air velocity over the water surface at all times.

The heat gains or losses resulting from convective and radiative effects are calculated as:

$$q_{conv} = (1 + 0.3V_p)(T_p - T_a)$$

where:

T_p = pool water temperature in degrees Rankine and
T_a = temperature of the air above the pool.

$$q_{rad} = \varepsilon\sigma(T_p^4 - T_{sky}^4)$$

where:

ε = pool emmisivity, taken as 0.9,
σ =the Stefan - Boltzmann constant, and
T_{sky} = the radiative sky temp.

The radiative sky temperature is the temperature of the conditioned air for enclosed pools or the ambient dry bulb for pools under a roof structure. For outdoor pools, the radiative sky temperature is a function of the air dry bulb and dewpoint temperatures, or:

$$T_{sky} = T_a\left[0.8 + \frac{\left(\frac{T_{dp}}{1.8} - 273\right)}{250}\right]^{0.25}$$

where:

T_{dp} = air dewpoint temperature in degrees Rankine.

For outdoor pools without a roof cover, the heat gain from solar energy incident on the pool is taken directly from global horizontal solar data from the average hourly weather data for Atlanta. We assume that 80% of the incident radiation is absorbed. We also assumed that 5% of the available solar radiation is absorbed by the pools covered by a roof structure, but not enclosed. No solar radiation credit is taken for pools once they are fully enclosed.

The heat loss or gain due to the addition of make-up water to replace that evaporated is found by balancing by the mass of water evaporated with the mass of the make-up water. Both masses are functions of their temperatures. The mass of water evaporated is equal to:

$$m_{evap} = {}^{q_{evap}}\!/_{h_{fg}}$$

where h_{fg} is the enthalpy of evaporation of the water at the pool water temperature. The heat transfer associated with the addition of make-up water is calculated as:

$$q_{makeup} = m_{evap} C_p (T_p - T_w)$$

where T_w is the temperature of the make-up water, assumed to equal the average monthly ground temperature at a depth of four feet.

During competitive events, we assume that the water temperature will be maintained within 1° F of the 78° F setpoint. Our assumption may result in a cooling load on the pool if convective and solar gains heat the pool above the setpoint. We also assume that, at other times (non-competitive use), the pools are only heated and that the pool temperature is allowed to rise above the nominal 78° F setpoint. In this latter case, the pool acts as a thermal storage tank, reducing the need for heating until the pool temperature is lowered to the setpoint. In calculating the pool's storage effects, we assume that the pool filter pumps keep the pool well-mixed and that there is a single average pool temperature.

The heat balance for the pool is evaluated hourly, based on hourly weather data obtained from a TMY (Typical Meteorological Year) weather file. This weather file provides statistically average drybulb & dewpoint temperatures, wind speed & direction, and global horizontal radiation for the Atlanta area. The source energy load required to heat or cool the pool is obtained by summing hourly thermal loads over the year, or

$$Q_{heat} = \sum_{t=1}^{8760} q_{source} \qquad \text{for } q_{source} < 0\text{, and}$$
$$Q_{cool} = \sum_{t=1}^{8760} q_{source} \qquad \text{for } q_{source} > 0.$$

The heating and cooling loads are met by heating and cooling equipment, assumed to operate at constant efficiencies. Heat is provided by a gas-fired water heater operating at an (assumed) average gas-to-heat conversion efficiency of 75%. Cooling is provided by electric chillers, assumed to operate at an average EER of 12.0. The high value of the assumed cooling EER is a result of the relatively high entering water temperature to the chiller evaporator (chillers are typically rated at a 45° F entering water temperature while the actual entering water temperature would be near 80° F).

SOLAR HEATING POTENTIAL CALCULATION APPROACH

The energy conversion efficiency of a solar collector is defined by ASHRAE Standard 96-1980, which is an empirical curve-fit expressed as:

$$\eta = a - bx - cx^2$$

where:

$$\eta = \text{efficiency} = \frac{\text{useful energy removed from the collector}}{\text{solar energy incident on the collector, in the plane of the array}}, \text{ and}$$

$$x = \frac{t_{f,i} - t_{amb}}{I}$$

and where:

$t_{f,i}$ = fluid inlet temperature, and

t_{amb} = ambient air temperature

The collector's power output is expressed by:

$$q = \eta I$$

where:

I = total solar radiation, in the plane of the array

The total solar radiation is modeled, conservatively, using global horizontal irradiance data obtained from a TMY (Typical Meteorological Year) weather file. This file provides statistically averaged hourly drybulb temperatures and global horizontal irradiances for Atlanta. Global horizontal radiation is used, without modification for directivity, because of the collectors' orientation, flat on the roof and without any support structure. The actual collection and conversion efficiencies should be better than the calculated, but nonetheless well within 10% of the model.

The collected energy is found by summing the hourly conversions over the year, or:

$$Q_{collected} = \sum_{i=1}^{8760} q_{hour} \quad \text{for } q_{hour} > 93 \text{ to } 123 \text{ btuh/sf}$$

The energy collected is limited to power output greater than the above thresholds, which correspond to a 2°F rise in the collector, which is a minimal control deadband.

ESTIMATE OF POOL ENERGY CONSUMPTION AND ENERGY COST SAVINGS

The energy consumption of the Natatorium's lap pool and diving well is shown in the following table. Energy consumption is shown for using thermally resistive pool covers whenever the pool is unused, and for leaving the pool surface free.

Chart 3-1: Energy Loss of Natatorium Pools

	Diving Well		Lap Pool	
	w/o Cover mbtu	w/Cover mbtu	w/o Cover mbtu	w/Cover mbtu
January	1,188	867	2,691	1,964
February	1,075	784	2,435	1,776
March	1,188	867	2,691	1,964
April	1,141	832	2,538	1,884
May	1,171	856	2,651	1,938
June	1,129	826	2,556	1,870
July	1,165	850	2,637	1,924
August	1,165	850	2,637	1,924
September	1,123	820	2,543	1,857
October	1,171	856	2,651	1,938
November	1,141	832	2,538	1,884
December	1,182	862	2,678	1,951
Annual	13,838	10,101	31,337	22,874

The energy cost savings below are based on the following unit energy costs: $0.40/therm gas cost; and $0.05/kWh electricity cost. The solar collector used in the model is the Heliocol/SunStar system, as they've offered to donate all of the collector materials. Heat, if it were provided by the Georgia Tech physical plant or by gas boilers, would be provided at a constant 75% efficiency. Pump mechanical efficiencies are assumed to be 86%; their motors' electrical efficiencies are assumed to be 92%. The solar collection system produces useful energy for 1291 hours per year. It is assumed that the filtering of the pool may be performed only when the solar collection system is producing useful heating energy to the pool[1]. Details of potential energy collection, energy cost savings, savings maximization and collector area sizing are provided in Appendix A and Appendix B. The installed cost for the solar collection system and pool interface heat exchangers is approximately $214,200 (for all-PVC piping), or $277,000 (for stainless- and black-steel piping)[2]. Details of the installation cost of the solar collection system is provided in Appendix D.

Chart 3-2: Summary Energy Cost Savings and Payback Calculations

	Pools w/o Covers	Pools w/Covers
Optimal Collector Area, sf	24,814	18,170
Actual Energy Collected, therms	42,017.0	30705.9
Solar Collection System Fluid Flow rate, gpm	3,050	2,233
Hours of Useful Collection/Hours of Filtration Run-Time	1,291	1,291
Gas Cost Savings, per year	$22,409	$16,376
Pool Filter Pump Costs, per year	$1,651	($1,651)
Solar Collection System Pump Costs, per year	$5,156	($3,775)
Net Energy Savings	$15,603	$10,951
Simple Payback, (on a steel piping basis)	18 years	25 years
Simple Payback, (on a PVC piping basis)	13 years	20 years

---

[1] this is not a trivial assumption; useful energy collection during the winter months are not guaranteed, and the timeclock nature of filtration control may also require non-coincident (in respect to the solar collection system) run-time of the pool pumps. This assumption does not err, if wrong, on the conservative side; if wrong, the pool pump costs (due to increased head) increase, decreasing the net energy cost savings of the system.

[2] these costs are associated with all piping below the roof level; everything above the roof is assumed to be part of the donated collector. Further, only an estimate of the piping to and from the pools' filtration piping is priced.

CONCLUSIONS

This feasibility study examines solar thermal applications for the Georgia Institute of Technology Natatorium. Issues specifically addressed in this study are: the solar potential of the site and collectors on the Natatorium's roof; the solar collection system's interface with the pools; an evaluation of the collectors' materials and compatibility; efficacy of the collection system; estimates of the system's installed costs and energy cost savings; and a simple payback calculation of such a system as applied to the Natatorium.

Thirteen solar collector manufacturers were interviewed, as well as many other (non-manufacturing) people in the industry. Hourly analyses, using Typical Meteorological Year data, to find the solar potential of the site as well as useful energy collected, were performed on the eight collection materials for which we received FSEC or SRCC ratings. Cost estimates were performed using 1994 Means Mechanical Cost Data.

Only the unglazed collectors were finally analyzed, as they are much less expensive to install and one manufacturer - Heliocol/SunStar - has offered to donate all of the collector materials required for the installation to the Georgia Institute of Technology. Unglazed collectors are fabricated of either EPDM or polypropylene, both of which have some faults: the EPDM can powder and leach into direct-connected pools; the polypropylene can become brittle and break with UV radiation. However, these collectors are simple to install and repair.

We project that it will cost from $214,000 to as much as $277,000 to install a solar collection system for the Natatorium, *exclusive of the collectors' material costs.* We project that the solar collection system will produce net energy cost savings equal to as much as $15,600 per year. We Calculate a simple payback for such a system to be as little as 13 to 20 years.

APPENDIX A: MONTHLY ENERGY COST SAVINGS MAXIMIZATION CALCULATIONS

The energy savings of the Heliocol/SunStar solar thermal technology is evaluated following, shown as a function of the collector area and whether or not the Natatorium pools have thermal blankets. The result of the analysis is that sizing the collection area slightly above the average month's *requirement* [1] is, in fact, the most efficient use of the solar thermal system. If one were to size the collection area for the largest *requirement* [2], the solar collection system's pumping costs would drive the net cost savings down. Size the collector area smaller, and less solar radiation would be collected to balance the pool filter pumps' demands.

---

[1] a function of the pool's energy loss and the usable energy out of the collector

[2] in our analysis, this was January: the pool load is relatively constant, but the useful energy collected is the least during this month

Energy Cost Savings Maximization Calculations, w/o Pool Cover

	Solar Collection, btu/h/sf	Pool Heating Load, btu/sf	Pool Heating Load, therm	Solar Collector Req'd Area	Solar System Req'd Flow	Case 1: 60% of maximum area req'd			Case 2: Average Area			Case 3: 57% of maximum area re		
						Actual Collection, @ 28,120 sf	Solar System Flow	Gas Cost Savings	Actual Collection, @ 19,557 sf	Solar System Flow	Gas Cost Savings	Actual Collection, @ 24,814 sf	Solar System Flow	Gas Cost Savings
January	9,016	20,000	3,824.8	43,530	5,350	2,355	3,210	$1,260	1,873	2,281	$892	2,237	3,050	$1,193
February	12,781	18,100	3,551.8	27,781	3,418	3,336	3,210	$1,780	2,372	2,281	$1,285	3,171	3,050	$1,681
March	26,180	20,000	3,824.8	18,867	1,916	3,825	1,916	$2,093	3,825	1,916	$2,093	3,825	1,916	$2,093
April	30,323	19,206	3,767.8	10,373	1,275	3,769	1,275	$2,008	3,768	1,275	$2,009	3,768	1,275	$2,008
May	47,674	19,700	3,868.9	8,129	999	3,868	999	$2,082	3,868	999	$2,082	3,836	938	$2,082
June	45,581	19,000	3,728.8	8,178	1,006	3,729	1,006	$1,989	3,729	1,005	$1,989	3,729	1,006	$1,989
July	48,280	19,600	3,840.3	7,965	979	3,840	979	$2,051	3,840	979	$2,051	3,840	979	$2,051
August	45,007	19,600	3,840.3	8,434	1,036	3,840	1,036	$2,051	3,840	1,036	$2,051	3,840	1,036	$2,051
September	31,808	18,900	3,708.9	11,660	1,433	3,709	1,433	$1,978	3,709	1,433	$1,978	3,709	1,433	$1,978
October	27,802	19,700	3,868.9	14,067	1,729	3,868	1,729	$2,082	3,868	1,729	$2,082	3,800	1,729	$2,082
November	15,108	19,209	3,767.8	24,937	3,065	3,788	3,065	$2,009	2,804	2,281	$1,495	3,748	3,050	$2,000
December	9,218	19,900	3,905.2	42,045	5,167	2,426	3,210	$1,294	1,724	2,281	$919	2,305	3,050	$1,229
Average	29,506	19,408	3,809	18,557		3,537								
Year	354,067	232,900	45,704.3											

19,624 sf of pool area
0.1228 GPM/sf water flowrate
$0.40 /therm
$0.05 /kWh
1281 Hours of Useful Collection
1281 Run-Time Hours for Filtration

	Case 1	Case 2	Case 3
	42,441.8 therms Saved	39,128.0 therm	42,017.0 therm
	$22,820 Gas Savings	$20,868 Gas Savings	$22,408 Gas Savings
	($1,851)Fixed Pool Pump Cost	($1,851)Fixed Pool Pump Cost	($1,851)Fixed Pool Pump Cost
	($5,427)Solar Side Pump Cost	($3,856)Solar Side Pump Cost	($5,156)Solar Side Pump Cost
	$15,568 Net Savings	$15,381 Net Savings	$15,603 Net Savings

Energy Cost Savings Maximization Calculations, w/Pool Cover

	Solar Collection, btu/h/sf	Pool Heating Load, btu/sf	Pool Heating Load, therm	Solar Collector Req'd Area	Solar System Req'd Flow	Case 1: 60% of maximum area req'd			Case 2: Average Area			Case 3: 57% of maximum area re		
						Actual Collection, @ 19,967 sf	Solar System Flow	Gas Cost Savings	Actual Collection, @ 13546.4 sf	Solar System Flow	Gas Cost Savings	Actual Collection, @ 18,170 sf	Solar System Flow	Gas Cost Savings
January	9,016	14,600	2,866.1	31,779	3,906	1,719	2,343	$917	1,221	1,664	$651	1,638	2,233	$874
February	12,781	13,200	2,590.4	20,207	2,491	2,437	2,343	$1,300	1,731	1,664	$923	2,322	2,233	$1,239
March	25,180	14,600	2,866.1	11,379	1,398	2,865	1,398	$1,528	2,865	1,398	$1,528	2,865	1,398	$1,528
April	38,323	14,000	2,747.4	7,584	930	2,747	930	$1,465	2,747	930	$1,465	2,747	930	$1,465
May	47,674	14,400	2,826.9	5,940	730	2,826	730	$1,507	2,826	730	$1,507	2,826	730	$1,507
June	45,581	13,900	2,727.7	5,983	735	2,728	735	$1,455	2,728	735	$1,455	2,728	735	$1,455
July	48,290	14,300	2,806.2	5,811	714	2,806	714	$1,497	2,806	714	$1,497	2,806	714	$1,497
August	45,607	14,300	2,806.2	6,153	758	2,806	758	$1,497	2,806	758	$1,497	2,806	758	$1,497
September	31,808	13,800	2,708.1	8,514	1,046	2,708	1,046	$1,444	2,708	1,046	$1,444	2,708	1,046	$1,444
October	27,602	14,400	2,826.9	10,276	1,263	2,826	1,263	$1,507	2,826	1,263	$1,507	2,826	1,263	$1,507
November	15,109	14,000	2,747.4	18,183	2,235	2,747	2,235	$1,465	2,046	1,664	$1,091	2,745	2,233	$1,464
December	9,288	14,500	2,845.5	30,830	3,785	1,771	2,343	$945	1,268	1,664	$671	1,888	2,233	$900
Average	29,506	14,167	2,780.1	13,540										
Year	354,067	170,000	33,360.9											

	Case 1	Case 2	Case 3
	30,961.9 therms saved	28,587.3 therms saved	30,796.8 therm
	$16,520 Gas Savings	$15,236 Gas Savings	$16,378 Gas Savings
	($1,851)Fixed Pool Pump Cost	($1,851)Fixed Pool Pump Cost	($1,851)Fixed Pool Pump Cost
	($3,902)Solar Side Pump Cost	($2,813)Solar Side Pump Cost	($3,775)Solar Side Pump Cost
	$10,614 Net Savings	$10,772 Net Savings	$10,851 Net Savings

APPENDIX B: MONTHLY ENERGY COLLECTION ESTIMATES FOR SOLAR THERMAL TECHNOLOGIES

The energy savings of various solar thermal collector technologies are evaluated following, shown as a function the isolation heat exchanger's approach. The energy collected is found by using FSEC or SRCC conversion efficiencies, evaluated on an hourly basis using Atlanta's TMY weather file.

Notable is that the heat exchanger de-rates the energy collected energy by only 1% per degree F of approach. Of further note is the clustering of the various unglazed technologies' collected energies, showing that price, longevity and suitability are more important in collector choice (than its efficiency).

Monthly Energy Collection Estimates for Solar Thermal Technologies Rev. 4, July 20, 1994

(No Heat Exchanger Applied to the System)

	Poly-Propylene or EPDM Pads					Glazed Collectors		
	Techno-Solis	Harter Spec.	Envir. Prod.	Heliocool/SunStar	Heliodyne	Radco	Thermomax	American Solar
btu/sf, yr	360,884	331,383	378,885	361,573	351,877	376,409	288,790	301,742
btu/sf, Jan	10,408	8,315	10,531	8,376	13,886	15,843	11,467	11,886
btu/sf, Feb	14,263	11,853	14,588	13,186	17,425	18,340	14,308	14,881
btu/sf, Mar	26,881	23,404	27,871	25,774	28,424	30,888	23,251	24,185
btu/sf, Apr	36,821	34,106	38,560	37,028	35,485	37,784	28,923	30,475
btu/sf, May	47,572	44,556	49,881	48,371	44,062	46,647	35,837	37,848
btu/sf, Jun	46,251	42,704	47,348	48,401	41,028	43,224	33,331	35,408
btu/sf, Jul	47,567	45,050	49,858	48,122	42,458	44,583	34,450	36,883
btu/sf, Aug	44,388	42,836	47,178	46,383	40,180	42,203	32,815	34,724
btu/sf, Sep	31,765	29,876	33,238	32,488	28,143	30,775	23,898	25,126
btu/sf, Oct	28,236	26,925	28,257	28,115	27,540	28,421	22,467	23,620
btu/sf, Nov	16,429	14,157	16,782	15,814	18,217	18,913	14,823	15,464
btu/sf, Dec	10,779	8,889	10,902	8,894	14,022	15,768	11,510	11,745

(1 deg F Exchanger Applied to the System)

	Poly-Propylene or EPDM Pads					Glazed Collectors		
	Techno-Solis TS-48	Harter Spec. Hi-Temp	Envir. Prod. Sun Master	Heliocool/SunStar STR-40	Heliodyne Gobi 408	Radco 412P-HP	Thermomax THS 200	American Solar Network ASN-60
btu/sf, yr	357,990	327,847	372,995	357,804	351,818	378,165	288,238	301,012
btu/sf, Jan	10,245	8,131	10,358	8,194	13,861	15,828	11,461	11,836
btu/sf, Feb	14,090	11,842	14,412	12,986	17,381	18,324	14,274	14,833
btu/sf, Mar	26,442	23,318	27,106	25,474	28,368	30,867	23,210	24,123
btu/sf, Apr	36,651	33,794	38,271	36,675	35,427	37,762	28,886	30,410
btu/sf, May	47,275	44,207	49,330	47,871	43,896	46,622	35,794	37,875
btu/sf, Jun	44,947	42,369	46,967	46,968	40,962	43,210	33,769	35,333
btu/sf, Jul	47,268	44,717	49,591	48,705	42,380	44,569	34,410	36,620
btu/sf, Aug	44,703	42,312	46,837	46,886	40,121	42,182	32,579	34,869
btu/sf, Sep	31,536	29,576	32,932	32,162	28,067	30,764	22,651	25,062
btu/sf, Oct	27,907	26,836	28,892	27,908	27,488	29,402	22,433	23,564
btu/sf, Nov	16,223	13,926	16,557	15,361	18,170	18,896	14,868	15,402
btu/sf, Dec	10,593	8,363	10,719	9,400	13,876	15,750	11,474	11,695

(2 deg F Exchanger Applied to the System)

	Poly-Propylene or EPDM Pads					Glazed Collectors		
	Techno-Solis TS-48	Harter Spec. Hi-Temp	Envir. Prod. Sun Master	Heliocool/SunStar STR-40	Heliodyne Gobi 408	Radco 412P-HP	Thermomax THS 200	American Solar Network ASN-60
btu/sf, yr	355,076	324,882	368,839	354,067	350,648	376,820	285,804	300,282
btu/sf, Jan	10,062	7,848	10,158	8,016	13,906	15,808	11,414	11,586
btu/sf, Feb	13,917	11,432	14,238	12,761	17,338	18,307	14,241	14,586
btu/sf, Mar	26,218	23,020	26,845	25,180	28,311	30,848	23,168	24,061
btu/sf, Apr	36,384	33,463	38,001	36,323	35,370	37,741	28,847	30,348
btu/sf, May	46,878	43,854	49,000	47,574	43,630	46,598	35,760	37,802
btu/sf, Jun	44,645	42,017	46,629	46,881	40,887	43,186	33,847	35,260
btu/sf, Jul	46,967	44,379	49,227	48,290	42,325	44,546	34,370	36,647
btu/sf, Aug	44,420	41,988	46,490	45,607	40,063	42,161	32,543	34,583
btu/sf, Sep	31,277	29,274	32,627	31,806	28,031	30,734	23,615	25,001
btu/sf, Oct	27,760	25,348	28,731	27,502	27,439	29,383	22,400	23,506
btu/sf, Nov	16,018	12,673	16,334	15,100	18,124	18,879	14,854	15,350
btu/sf, Dec	10,414	8,182	10,520	8,268	13,930	15,733	11,437	11,644

(5 deg F Exchanger Applied to the System)

	Poly-Propylene or EPDM Pads					Glazed Collectors		
	Techno-Solis TS-48	Harter Spec. Hi-Temp	Envir. Prod. Sun Master	Heliocool/SunStar STR-40	Heliodyne Gobi 408	Radco 412P-HP	Thermomax THS 200	American Solar Network ASN-60
btu/sf, yr	348,452	314,310	358,270	343,014	348,701	375,188	284,212	299,100
btu/sf, Jan	9,610	7,386	9,881	8,486	13,768	15,756	11,303	11,438
btu/sf, Feb	13,408	10,831	13,730	12,179	17,208	18,258	14,139	14,441
btu/sf, Mar	25,601	22,165	26,076	24,314	28,143	30,782	23,043	23,870
btu/sf, Apr	35,881	32,487	37,210	35,260	35,188	37,679	28,731	30,154
btu/sf, May	46,000	42,785	47,884	46,380	43,733	46,524	35,820	37,584
btu/sf, Jun	43,758	40,878	45,563	44,408	40,702	43,114	33,118	35,043
btu/sf, Jul	46,068	43,343	48,187	47,080	42,130	44,472	34,247	36,330
btu/sf, Aug	43,867	40,911	45,479	44,460	39,838	42,087	32,434	34,307
btu/sf, Sep	30,507	28,352	31,727	30,779	28,863	30,672	23,502	24,818
btu/sf, Oct	27,058	24,480	27,968	26,584	27,289	29,320	22,290	23,342
btu/sf, Nov	15,415	12,828	15,870	14,365	17,045	18,828	14,748	15,185
btu/sf, Dec	9,891	7,578	9,870	6,700	13,793	15,680	11,326	11,494

APPENDIX C: LITERATURE SEARCH

POOL THERMAL CHARACTERISTICS

1. --, *1991 Applications*, ASHRAE, Atlanta, GA 1991 (pp. 4.6-4.8: Natatoriums)
2. --, *Analysis Procedures, Reducing Swimming Pool Energy Costs Computer Simulation Program*, August, 1993.
3. M. Shah, *Calculating Evaporation from Pools and Tanks*, Heating/Piping/Air Conditioning, April 1992.
4. Jones, R.W., Smith, C.C., Löf, G., Measurement and Analysis of Evaporation from an Inactive Outdoor Swimming Pool, *Solar '93, Proceedings of the 1993 Annual Conference of the American Solar Energy Society*, Washington, D.C., April, 1993
5. Smith, C. C., Jones, R. W., Löf, G., Energy requirements and potential savings for heated indoor swimming pools, *1993 ASHRAE Transactions*, v.99, Pt. 2, Symposia paper number DE-93-12-3, 1993.
6. Smith C. C., Final Report: *Measurement of Energy and Evaporation in Swimming Pools as a Function of Activity Level*, Report to the U.S. Department of Energy, Denver Support Office, October, 1993.

SOLAR THERMAL LITERATURE AND PAPERS

1. Duffie & Beckman, *Solar Engineering of Thermal Processes*, John Wiley & Sons, New York, NY, 1980.
2. Mossman, M.J., et al, *1994 Means Mechanical Cost Data*, R.S. Means Company, Kingston, MA, 1994.
3. --, *1991 Applications*, ASHRAE, Atlanta, GA 1991 (Chapter 30: Solar Energy Utilization).
4. --, *1992 Systems and Equipment*, ASHRAE, Atlanta, GA 1992 (Chaptor 34: Solar Energy Equipment).
5. --, *ASHRAE Standard 93-1986 (RA 91): Methods of Testing to Determine the Thermal Performance of Solar Collectors*, ASHRAE, Atlanta, GA, 1986.
6. --, *ASHRAE Standard 95-1981 (RA 87): Methods of Testing to Determine the Thermal Performance of Solar Domestic Water Heating Systems*, ASHRAE, Atlanta, GA, 1981.
7. --, *ASHRAE Standard 96-1980 (RA 89): Methods of Testing to Determine the Thermal Performance of Unglazed Flat-Plate Liquid-Type Solar Collectors*, ASHRAE, Atlanta, GA, 1980.
8. --, *Active Solar Heating Systems Design Manual*, ASHRAE, Atlanta, GA, 1988
9. --, *Active Solar Heating Systems Installation Manual*, ASHRAE, Atlanta, GA, 1991

10.--, Solar Domestic and Service Hot Water Manual. ASHRAE, Atlanta, GA, 1983

11.Root, D.E., Chandra, S., Cromer, C., et al, *Solar Water and Pool Heating Course Manual,* Florida Solar Energy Center, Cape Canaveral, FL.

12.--, *Test Methods and Minimum Standards for Certifying Solar Collectors,* Florida Solar Energy Center, Cape Canaveral, FL.

13.--, *Operation of the Collector Certification Program,* Florida Solar Energy Center, Cape Canaveral, FL.

14.Harter, D.G., Design Data for the Choice of Covers on Pool Panels, *Solar Engineering,* April 1979.

SALIENT BUILDING CODES AND STANDARDS

This below list is attached from internal RP+P working notes, listing all (that we could find) of the standards and codes which address aspects of unglazed solar thermal systems as they relate to the Natatorium. It is not written in a formal fashion, and many of the standards and codes may, in fact, not be applicable to the final design.

SMC, paragraph 309: Solar Energy Utilization. This paragraph in the Standard Mechanical Code describes safe practices and constructions for solar thermal collection systems.

ASTM D 15: Standard Methods for Compound and Sample Preparation for Physical Testing of Rubber Products. This standard addresses issues involved with the testing of EPDM products.

ASTM D 395: Standard Test Methods for Rubber Property-Compression Set. This standard addresses issues involved with the testing of EPDM products.

ASTM D 412: Standard Test Methods for Rubber Properties in Tension. This standard addresses issues involved with the testing of EPDM products.

ASTM D 573: Standard Test Method for Rubber-Deterioration in an Air Oven. This standard addresses issues involved with the testing of EPDM products.

ASTM D 624: Standard Test Method for Rubber Property-Tear Resistance. This standard addresses issues involved with the testing of EPDM products.

ASTM D 638: Standard Test Method for Tensile Properties of Plastics. This standard addresses issues involved with the testing of polypropylene products.

ASTM D 746: Standard Test Method for Brittleness Temperature of Plastics and Elastomers by Impact. This standard develops the temperature at which 50% of the sample plastics are brittle.

ASTM D 865: Standard Test Method for Rubber-Deterioration by Heating in Air (Test Tube Enclosure). This standard may address issues involved with the fabrication of the collectors.

ASTM D 925: Standard Test Methods for Rubber Property-Staining of Surfaces (Contact, Migration and Diffusion).

ASTM D 1149: Standard Test Method for Rubber Deterioration-Surface Ozone Cracking in a Chamber. This standard addresses issues involved with the testing of EPDM products.

ASTM D 1763: Standard Specifications for Epoxy Resins. This standard may address issues involved with any epoxied connections in the collectors.

ASTM D 3039: Standard Test Method for Tensile Properties of Fiber-Resin Composites. We came across this standard by reference.

ASTM E 838: Standard Practices for Performing Accelerated Outdoor Weathering Using Concentrated Natural Sunlight. This standard describes testing for weathering, under sunlight, of plastics, like polypropylene.

ASTM G 90: Standard Practices for Performing Accelerated Outdoor Weathering of Nonmetallic Materials Using Concentrated Natural Sunlight. This standard describes testing for weathering, under sunlight, of plastics, like polypropylene.

APPENDIX D: COST ESTIMATE WORKSHEETS

Two cost estimates were performed: one uses stainless steel piping in the pool water side and black steel in the solar collection system side; the other uses schedule 40 PVC piping in both systems. An assumption is made that no pool covers will be used, and that the solar collection system's fluid flow rate is equal to 3,050 gpm. A further assumption is made to include a drainback tank and dump valves for the solar collection system's freeze protection. Two isolation heat exchangers are included, one for the lap pool, and the other for the diving well.

Cost Estimate to Incorporate the Solar Thermal Heating System into the Natatorium Pools

Means' #	Item	Qty	Unit Costs			Extended Costs		
			Material	Labor & Equipment	Total (1)	Material	Labor & Equipment	Total (1)
132.051.3120	Labor to Mount Solar Collectors	18750	$0.00	$3.45	$5.18	$0.00	$64,687.50	$97,031.25
132.051.3120	Storage Tank, 1600 gal	1	$1,700.00	$288.00	$2,325.00	$1,700.00	$288.00	$2,325.00
152.430.3180	Horiz. Split-Case Pumps, 75 hp ea	2	$7,950.00	$2,875.00	$13,200.00	$15,900.00	$5,750.00	$26,400.00
	Plate & Frame H/X's, SS, for the 2 pools	2	$26,445.00	$2,385.00	$33,000.00	$52,890.00	$4,770.00	$66,000.00
151.701.0700	Black Steel Piping, Sch. 40, 12"	400	$68.50	$35.00	$129.00	$27,400.00	$14,000.00	$51,600.00
151.701.0690	Black Steel Piping, Sch. 40, 10"	60	$54.50	$27.50	$102.00	$3,270.00	$1,650.00	$6,120.00
151.701.0680	Black Steel Piping, Sch. 40, 8"	60	$34.50	$5.00	$74.00	$2,070.00	$300.00	$4,440.00
151.720.3170	BS Elbow, sch 40, Welded, 12"	8	$197.00	$274.50	$625.00	$1,576.00	$2,196.00	$5,000.00
151.720.3160	BS Elbow, sch 40, Welded, 10"	6	$138.00	$228.05	$490.00	$828.00	$1,368.30	$2,940.00
151.720.3150	BS Elbow, sch 40, Welded, 8"	6	$77.00	$171.80	$340.00	$462.00	$1,030.80	$2,040.00
151.720.4609	BS Tee, reducing, 12"x10"	4	$340.00	$427.00	$1,025.00	$1,360.00	$1,708.00	$4,100.00
151.720.3480	BS Tee, 12"x12"	2	$268.00	$427.00	$935.00	$536.00	$854.00	$1,870.00
151.960.2360	Gate Valves, Iron, 12"	2	$2,450.00	$375.00	$3,275.00	$4,900.00	$750.00	$6,550.00
151.960.2340	Gate Valves, Iron, 10"	2	$1,800.00	$288.00	$2,425.00	$3,600.00	$576.00	$4,850.00
151.960.2320	Gate Valves, Iron, 8"	2	$1,025.00	$254.00	$1,279.00	$2,050.00	$508.00	$2,558.00
151.960.4610	Globe Valves, Iron, 8"	2	$1,500.00	$254.00	$2,025.00	$3,000.00	$508.00	$4,050.00
151.960.5120	Globe Valves, Iron, 10"	2	$2,300.00	$315.00	$3,000.00	$4,600.00	$630.00	$6,000.00
	Globe Valves, Iron, 12"	3	$2,700.00	$350.00	$3,400.00	$8,100.00	$1,050.00	$10,200.00
151.960.6080	Check Valves, Iron, 8"	2	$700.00	$254.00	$1,150.00	$1,400.00	$508.00	$2,300.00
156.201.0340	Automatic Air Vent	4	$295.00	$22.50	$360.00	$1,180.00	$90.00	$1,440.00
156.205.0160	Air Control, w/Strainer, 8"	2	$2,450.00	$211.00	$3,025.00	$4,900.00	$422.00	$6,050.00
156.225.0240	Expansion/Vibration Joint	4	$385.00	$75.50	$540.00	$1,540.00	$302.00	$2,160.00
151.601.5220	Stainless Piping, sch. 40, 12"	300	$133.00	$34.06	$197.00	$39,900.00	$10,218.00	$59,100.00
151.612.0280	SS Elbow, welded, 12"	4	$555.00	$437.50	$1,250.00	$2,220.00	$1,750.00	$5,000.00
151.612.1270	SS Tee, welded, 12"x12"	2	$795.00	$491.50	$1,600.00	$1,590.00	$983.00	$3,200.00
151.980.2100	Steel Gate Valve, 12"	4	$4,350.00	$375.00	$5,350.00	$17,400.00	$1,500.00	$21,400.00
	Controls	1	$4,000.00	$3,000.00	$7,000.00	$4,000.00	$3,000.00	$7,000.00
SUMS						$208,372.00	$56,710.10	$314,693.00
Means' Site Multiplier, Division 15 for Atlanta								88%
Total Project Cost								$276,929.84

Note: 1. The Total Cost figure in the Means data includes overhead & profit for the Contractor

GIT Solar Thermal Cost Estimate   Rev. #3, 8/4/94   HMS   JNDS #94410.1

Replace Steel Piping with PVC Piping

Means' #	Item	Qty	Unit Costs			Extended Costs		
			Material	Labor & Equipment	Total (1)	Material	Labor & Equipment	Total (1)
132.051.3120	Labor to Mount Solar Collectors	18750	$0.00	$3.45	$5.18	$0.00	$64,687.50	$97,031.25
132.051.3120	Storage Tank, 1600 gal	1	$1,700.00	$288.00	$2,325.00	$1,700.00	$288.00	$2,325.00
152.430.3180	Horiz. Split-Case Pumps, 75 hp ea	2	$7,950.00	$2,875.00	$13,200.00	$15,900.00	$5,750.00	$26,400.00
	Plate & Frame H/X's, SS, for the 2 pools	2	$26,445.00	$2,385.00	$33,000.00	$52,890.00	$4,770.00	$66,000.00
151.551.0800	PVC Piping, Sch. 40, 12"	400	$46.00	$15.10	$73.50	$18,400.00	$6,040.00	$29,400.00
151.551.0790	PVC Piping, Sch. 40, 10"	60	$35.00	$14.75	$61.50	$2,100.00	$885.00	$3,690.00
151.551.0780	PVC Piping, Sch. 40, 8"	60	$12.05	$13.20	$33.50	$723.00	$792.00	$2,010.00
	PVC Elbow, sch 40, 12"	8	$200.00	$170.00	$450.00	$1,600.00	$1,360.00	$3,600.00
	PVC Elbow, sch 40, 10"	6	$130.00	$120.00	$325.00	$780.00	$720.00	$1,950.00
151.558.0630	PVC Elbow, sch 40, 8"	6	$62.00	$70.50	$175.00	$372.00	$423.00	$1,050.00
151.558.0920	PVC Tee, 12"x12"	6	$675.00	$211.00	$1,075.00	$4,050.00	$1,266.00	$6,450.00
151.960.2360	Gate Valves, iron, 12"	2	$2,450.00	$375.00	$3,275.00	$4,900.00	$750.00	$6,550.00
151.960.2340	Gate Valves, iron, 10"	2	$1,800.00	$288.00	$2,425.00	$3,600.00	$576.00	$4,850.00
151.960.2320	Gate Valves, iron, 8"	2	$1,025.00	$254.00	$1,279.00	$2,050.00	$508.00	$2,558.00
151.960.4610	Globe Valves, iron, 8"	2	$1,500.00	$254.00	$2,025.00	$3,000.00	$508.00	$4,050.00
151.960.5120	Globe Valves, iron, 10"	2	$2,300.00	$315.00	$3,000.00	$4,600.00	$630.00	$6,000.00
	Globe Valves, iron, 12"	3	$2,700.00	$350.00	$3,400.00	$8,100.00	$1,050.00	$10,200.00
151.960.6080	Check Valves, iron, 8"	2	$700.00	$254.00	$1,150.00	$1,400.00	$508.00	$2,300.00
156.201.0340	Automatic Air Vent	4	$295.00	$22.50	$360.00	$1,180.00	$90.00	$1,440.00
156.205.0160	Air Control, w/Strainer, 8"	2	$2,450.00	$211.00	$3,025.00	$4,900.00	$422.00	$6,050.00
156.225.0240	Expansion/Vibration Joint	4	$385.00	$75.50	$540.00	$1,540.00	$302.00	$2,160.00
151.551.0800	PVC Piping, Sch. 40, 12"	300	$46.00	$15.10	$73.50	$13,800.00	$4,530.00	$22,050.00
	PVC Elbow, sch 40, 12"	4	$200.00	$170.00	$450.00	$800.00	$680.00	$1,800.00
151.558.0920	PVC Tee, 12"x12"	2	$675.00	$211.00	$1,075.00	$1,350.00	$422.00	$2,150.00
151.980.2100	Steel Gate Valve, 12"	4	$4,350.00	$375.00	$5,350.00	$17,400.00	$1,500.00	$21,400.00
	Controls	1	$4,000.00	$3,000.00	$7,000.00	$4,000.00	$3,000.00	$7,000.00
SUMS						$171,135.00	$37,770.00	$243,433.00
Means' Site Multiplier, Division 15 for Atlanta								88%
Total Project Cost								→ $214,221.04

Note: 1. The Total Cost figure in the Means data includes overhead & profit for the Contractor

RCVISED INFORMATION (
FEASIBILITY STUDY.

Roger Preston + Partners
CONSULTING MECHANICAL
AND ELECTRICAL ENGINEERS
7000 Central Parkway · Suite 1470
Atlanta, GA 30328

FACSIMILE MEMORANDUM

TO: **Mr. Richard Long, Georgia Institute of Technology**
FAX NO: **(404) 853-9319**
FROM: **Harris Sheinman, P.E.**
DATE: **September 8, 1994**
PROJECT & NO: **GIT Solar Thermal Study, 94410**
RE: **Cost Estimate Reconciliation**
PAGES: **2**
COPIES TO: **Ed Ney; Dan Nall; file**

This fax was sent from Roger Preston + Partners, fax number (404) 551-2157. Any problems with reception should be reported to telephone number (404) 551-2173.

Per request by the Department of Energy, please find below the cost estimate and schematic design methodology used in our report, An Evaluation of Solar Thermal pool Water Heating Systems for the Georgia Institute of Technology Natatorium, issued August 9,1994. Specifically, we were to address the inclusion of the plate & frame heat exchangers de-coupling the solar collection system form the pool water systems.

We performed schematic design for the report using unglazed collectors as the basis for the design. Because unglazed collectors as a group may be fabricated of polypropylene, EPDM, or both materials, the heat exchangers are necessary for prevention of black pools from the EPDM or encapsulated EPDM materials. If Georgia Tech elects to use collectors *fabricated of only polypropylene* (such as those manufactured by Heliocol), the threat of black pools is eliminated, and the heat exchangers are so unnecessary. Georgia Tech might wish to note that other unglazed collector manufacturers have also offered to donate collector materials.

Another issue collateral with the black pool threat is that the diving tank and the lap pool filter systems, according to local swimming pool codes, may not be served by any system which will intermix water from the two pools. They are currently designed as separate systems. Thus, if Georgia Tech elects to use collectors fabricated of only polypropylene, and also to remove the heat exchangers, *each solar collector system may be attached to only one of the pools*. We suggest the indoor lap pool be connected if the system is to be installed at the least, as that pool can not have a pool cover mounted on it. A second system, separate from that serving the lap pool, may be installed for the diving tank.

Another issue to be considered in the close-coupling of the pool water systems with the solar collection systems is that, if PVC piping is not to be used inside the Natatorium, only stainless steel piping may be used to carry the pool water up to the roof for solar heating. The chlorine in the water will damage black steel piping. Stainless steel piping up to the roof will be prohibitively expensive.

A last issue is the proposed turnkey installation by Heliocol, separate from the construction of the Natatorium. Such an installation can perhaps remove the General Contractor's mark-up on the work, and has been offered as another opportunity for cost savings.

If Georgia Tech elects to install unglazed collectors fabricated of only polypropylene in two separately-piped systems (one for the lap pool and one for the diving tank), and if Georgia Tech elects to use Heliocol as a turnkey supplier for the system without supervision by the Natatorium's General Contractor, the installed cost for the solar thermal collection system, not including the donated solar collectors, should be $133,973.40 for a system using PVC piping up to the roof. We again do not recommend using black steel piping up to the roof, as the chlorine in the coupled pool water/collector water will damage the piping. The energy save for the systems increases as well, as the filter pumps' heads are not increased to overcome the heat exchangers' pressure drops.

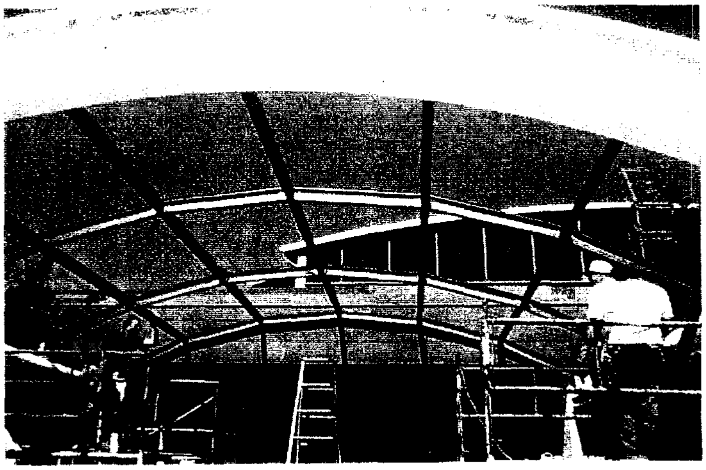
These savings, without the heat exchangers, range from $12,602 to $17,254. The simple payback for a solar collection system shortens to as little as 7.8 years.

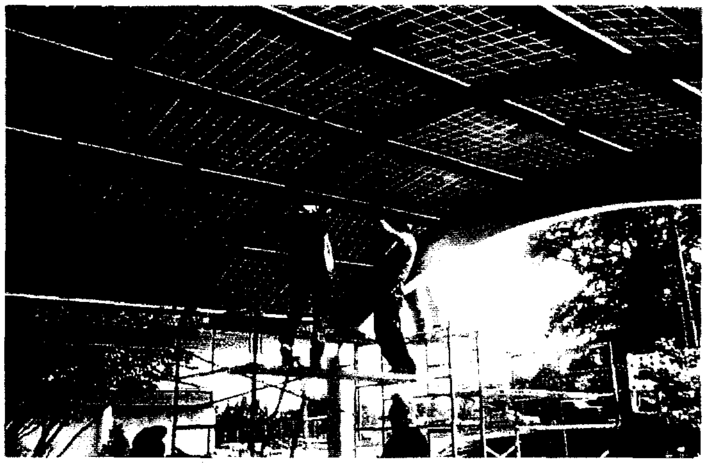
Please call me if you have any questions.

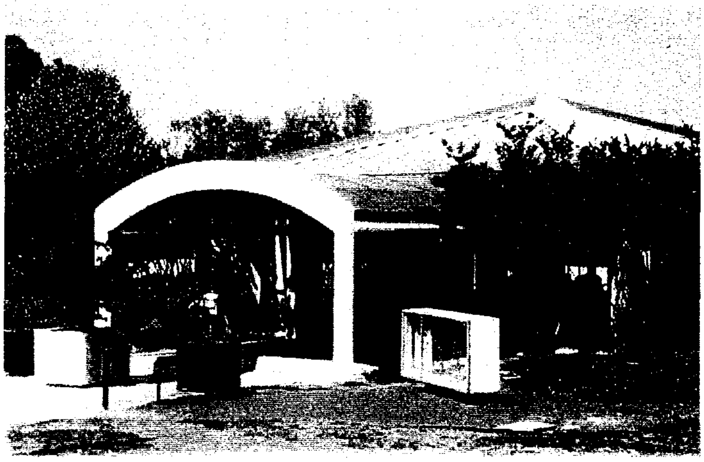
APPENDIX B
SAC ENTRANCE CANOPY MOCKUP

To test the feasibility and production of the PV system, a canopy mockup for the entrance to the Calloway Student Athletic Complex (SAC) adjacent to GTAC was designed. Not only would it function as a test run for the main photovoltaic system, but it would also shield entrants of SAC from the elements. The mockup was intended to be a prototype but was actually constructed after the main roof system was installed and became a showcase for emerging PV product technology.

The mockup system is not an exact replica of the GTAC roof system. While modules were still supplied by Solarex and polycrystalline, they were a different size (3'-8" x 6'-4") and contained AC/DC inverters on each individual module rather than having DC current fed to a main inverter within SAC. Furthermore, the eighteen 250W modules that make up the 14'x22' canopy were attached in a Kawneer manufactured aluminum curtain wall system. The allowance for the project was $79,281 to produce this 4.5 kW array.







APPENDIX C
PV FEASIBILITY STUDY

JND *STERLING*

REPORT OF THE FEASIBILITY OF IMPLEMENTING AN INTEGRATED PHOTOVOLTAIC/ROOF ARRAY

Prepared by

JND STERLING, INC.
Building Energy Engineers

7000 Central Parkway, Suite 1470
Atlanta, Ga 30328

Tel (404) 551-2150

Table of Contents

Abstract

DOE awarded to Advanced Photovoltaic Systems a PV:Bonus procurement for integrating a utility-interconnected photovoltaic system into a building component at a site in Atlanta in time for the 1996 Summer Olympics. Georgia Power Company, The Georgia Institute of Technology, and JND Sterling were named as strategic partners in the effort. This PV/Roof Integration Feasibility Study for the Georgia Tech Natatorium/Olympic aquatic venue is the initial product of the strategic partners' interest in the project. The Natatorium's massing, roof skin, roof structure, photovoltaic array, and power generation components are conceptually defined. Technical issues relating to photovoltaics, inverters, power conditioning, and safety are addressed. The photovoltaic array's energy and power production in the first year are estimated to be 569 MWh and 336 kW, respectively. The integrated PV/roof is expected to cost between $5.1 million to $6.4 million; the added cost for integrating the photovoltaic system onto a minimal roof over the Natatorium is expected to be $2.3 million to $3.5 million.

Introduction

History of Project

In the 4th quarter, 1992, the Department of Energy (DOE) issued a procurement for photovoltaic implementation, called PV:Bonus. JND Sterling (JNDS) and Advanced Photovoltaic Systems (APS) together responded to this procurement on November 16, 1993, naming Georgia Power Company and Georgia Institute of Technology as strategic participating interests. Georgia Power's interest in the project illustrates the company's long-standing commitment to Demand Side Management. The Georgia Institute of Technology's interest developed from the research opportunities and status of such an advanced-technology project. The DOE awarded the PV:Bonus procurement to APS on March 12, 1993, but also notified APS that federal funding was not yet available, placing the JNDS/APS response on hold.

In anticipation of the 1996 Olympic Games and DOE complementary funding, continued interest was provided by both the Georgia Power Company and the Georgia Institute of Technology. In a meeting on March 30, 1993, it was determined that the Georgia Institute of Technology Natatorium (see Description of Natatorium, below), to be used as the swimming venue for the Olympic Games, was an appropriate target for the photovoltaic system's installation/ implementation. The Georgia Power Company and The Georgia Institute of Technology committed to this concept in April, 1993. A/E selection, site selection and basic programming tasks occurred during the summer of 1993. On August 25, 1993, JNDS submitted a proposal to Georgia Power Company to provide a feasibility study and design criteria for the PV:Bonus implementation at the Natatorium.

Description of Natatorium

The Georgia Institute of Technology Natatorium will be an [approximate] 62,000 square-foot (sf) enclosed competitive swimming and diving facility composed of: a 25m x 25 yd diving tank; a 25m x 50m swimming pool; pool decks; 4000 permanent seats; and ~28,000 sf of space for student use. The Natatorium will be set adjacent to the Callaway Student Athletic Center, in the place of the existing indoor pool (see figures 1 and 2, following). The Natatorium will be used, in various forms, for the swimming venues of the 1995 Pan Pacific Games, 1996 Olympic Games, and the 1996 Paralympic Games. Its phases' descriptions follow (please see figure 3, following):

Phase One, Initial Construction (May, 1994 through July, 1995):

* demolition of the existing indoor pool and site
* temporary enclosure of the existing outdoor pool for continued student use
* construction of the 25m x 25 yd diving tank, the 25m x 50m swimming pool; pool decks; 4000 permanent seats; and ~28,000 sf of support space.
* this facility shall be used for the Pan Pacific Games in August, 1995.

Phase Two, Swimming Venue Preparation, for the Olympic Games (September 1995 through June 1996):

* add 11,000 temporary seats
* re-configure 49,000 sf of the existing Callaway Student Athletic Center as support space
* provide 110,000 sf of temporary support space on site

(text continued on page 6)

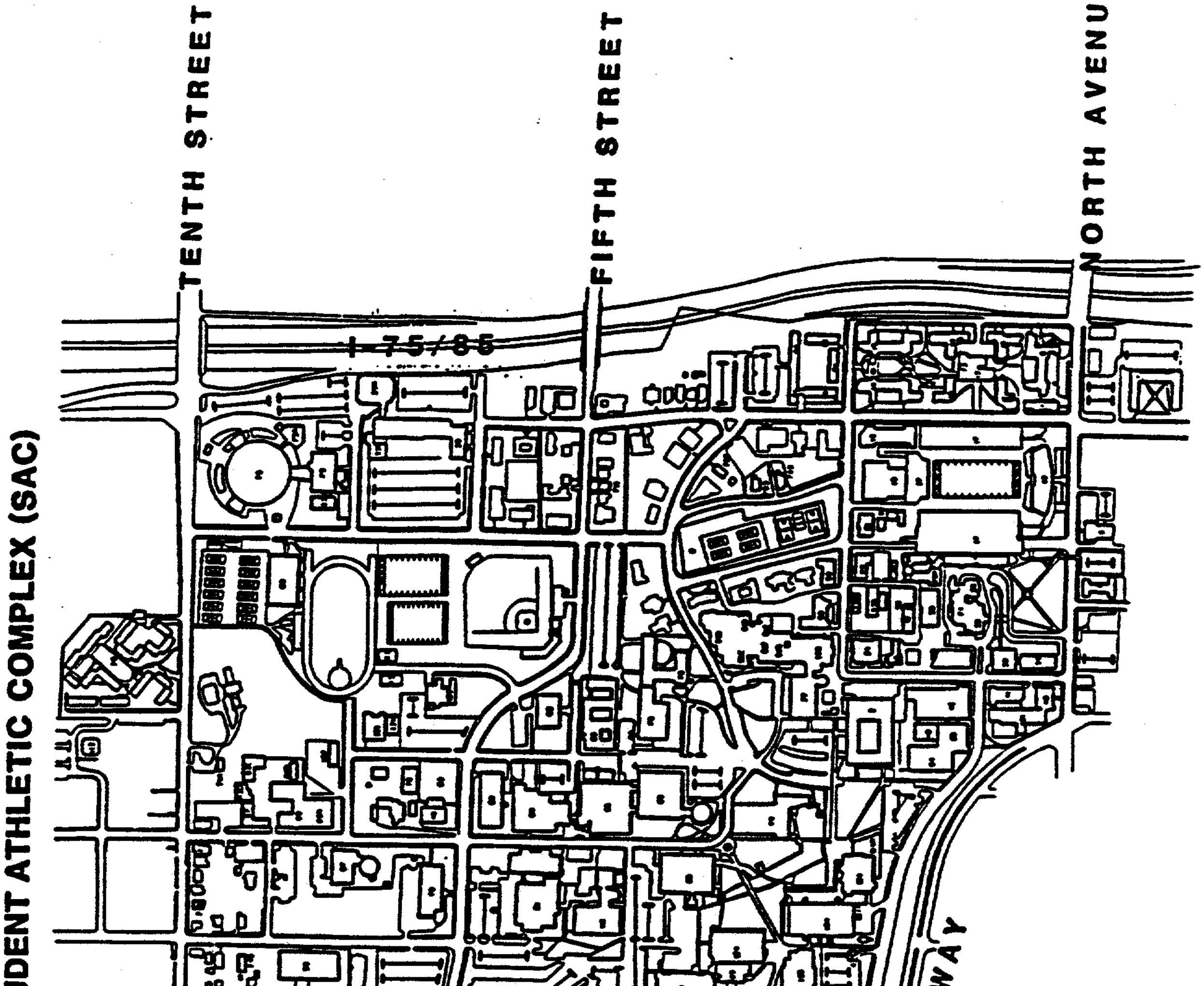


Figure 1: Georgia Institute of Technology Campus Location Map

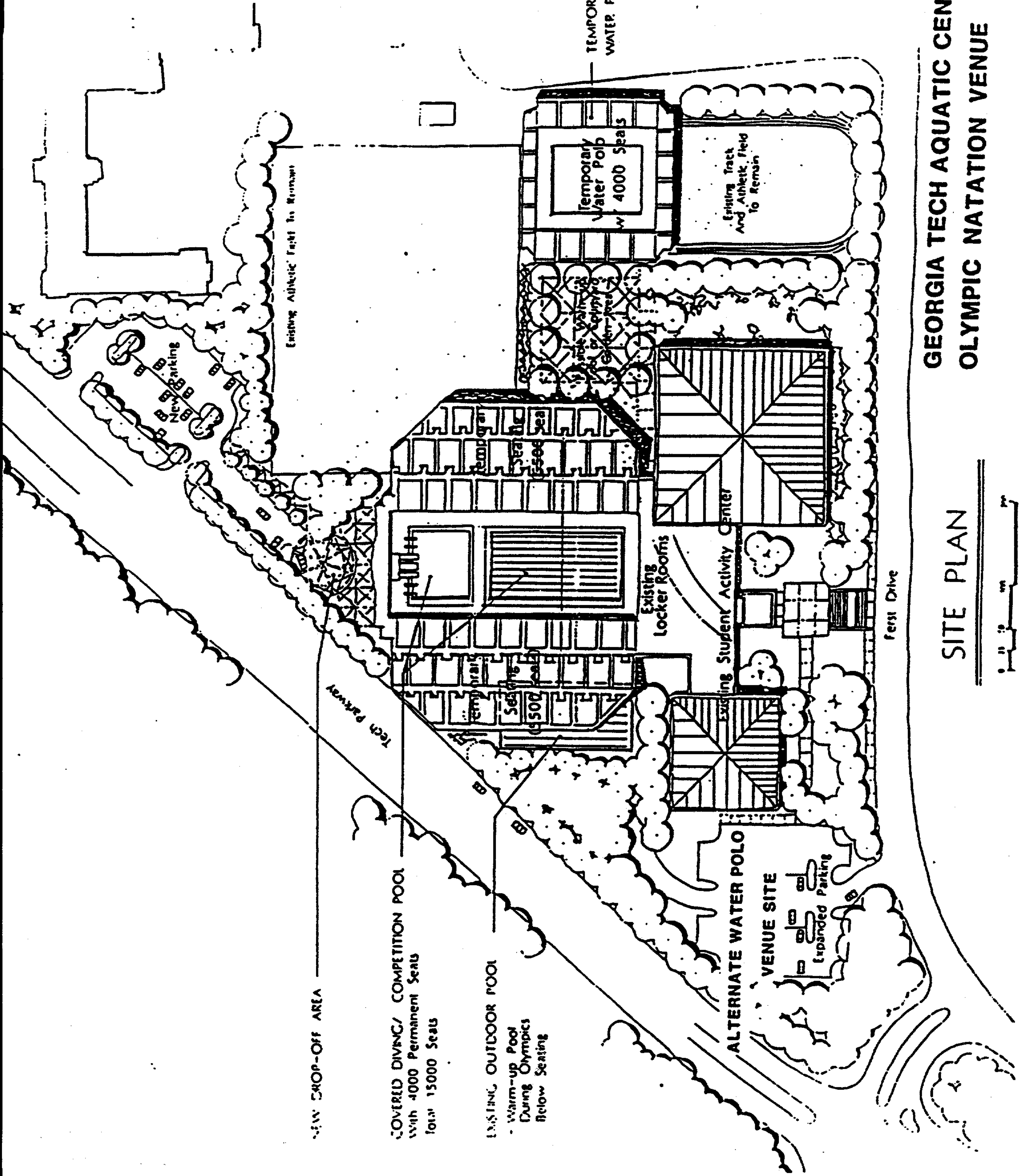
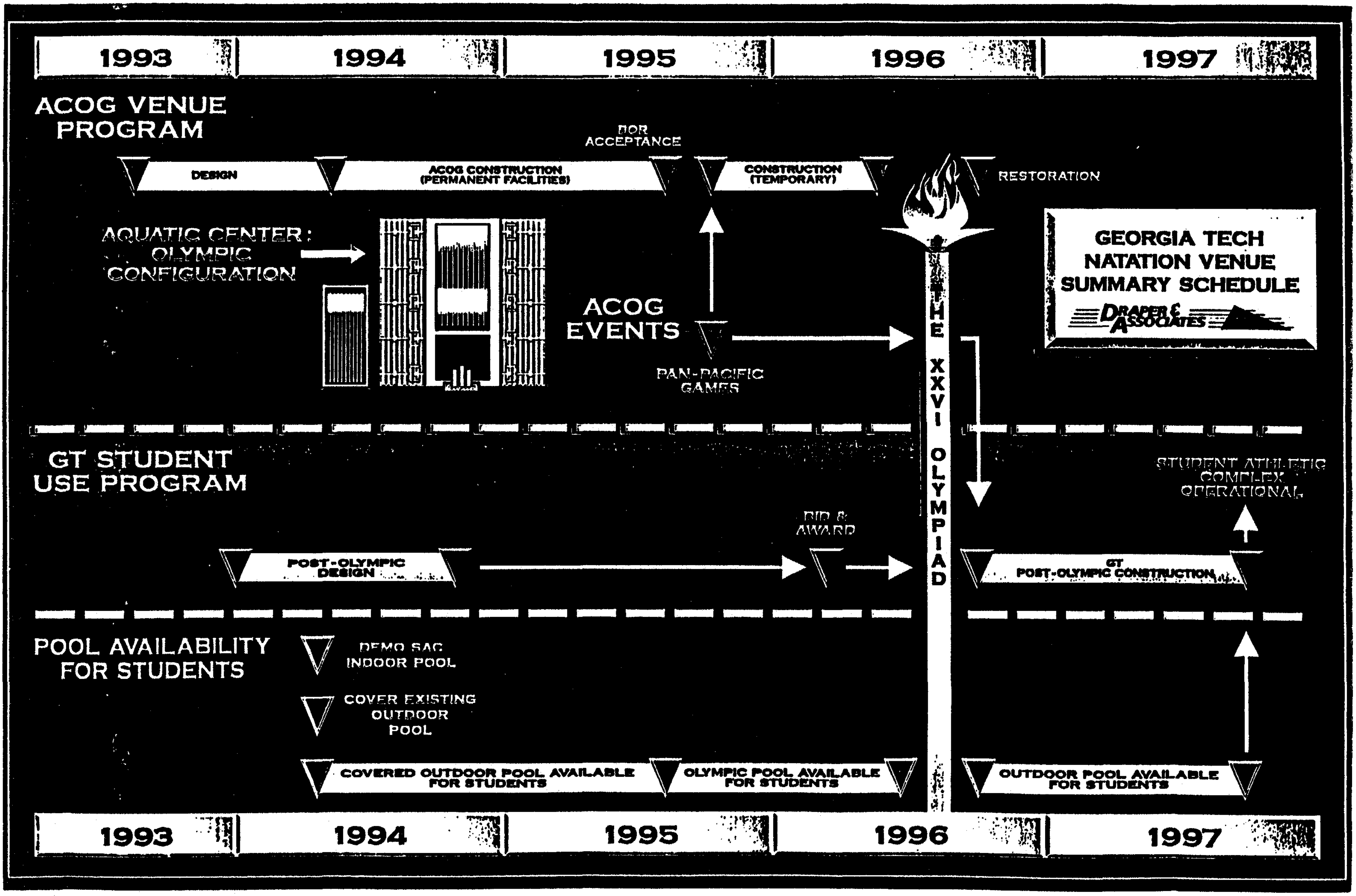


Figure 2: Georgia Tech Aquatic Center Olympic Natation Venue

GEORGIA TECH NATATION VENUE SUMMARY SCHEDULE

Draper & Associates



- construction of temporary covered decks and roofs for the Olympic Games.
- this facility shall be used for the Olympic Games in August, 1996, as well as the following Paralympic Games in September, 1996.

Phase Three, Post Olympic Student Program (October 1996 through life of facility):

- construction of the total enclosure of the diving tank, the competition pool, the pool decks. and the 4,000 permanent seats
- retrofit of the ~28,000 sf support space to student use space
- construction of the enclosed Natatorium's electrical and heating, ventilating and air-conditioning systems.

The integrated photovoltaic/roof system may be constructed during either phases one or two, in time for the Olympic Games.

Scope of Report

The professional services proposal sent to Georgia Power on August 25, 1993, included three distinct tasks: a conceptual feasibility study for the application of photovoltaics to the Georgia Institute of Technology Natatorium; schematic design support for the Natatorium design team; and a protocol for monitoring, testing and performance verification of the photovoltaic system.

This report is the product of the conceptual feasibility study, and is designed to assist The Georgia Power Company and The Georgia Institute of Technology in their decisions to further support the photovoltaic system's implementation. To that end, several project-specific issues are addressed, including:

- salient building codes, standards, as well as IEEE standards
- roof aesthetic and programmatic criteria -- weatherproofing, detailing, daylighting, glare control, skin condensation and acoustics;
- Natatorium block hvac and electrical loads (post-Olympics);
- structural design criteria and detailing
- electrical production systems -- inverters, blocking diodes, dc wiring criteria;
- electrical protection requirements -- harmonics, maintenance and system protection;
- expected energy and power production; and, most importantly,
- cost estimates of the implementation and construction of the photovoltaic system.

While the report does list a literature search, it does *not* evaluate the physical (re: p-n junction) working of the APS material, nor its technical merits. The report does however list this [cited] information, for ease of evaluation.

Description of Abbreviations

Abbreviation	Company
GIT	Georgia Institute of Technology
GPC	Georgia Power Company
JNDS	JND Sterling
APS	Advanced Photovoltaic Systems, Inc.
ACDT	Aquatic Center Design Team: Smallwood, Reynolds, Stewart Stewart & Associates; Stanley-Love-Stanley
PTC	Project Time & Cost (estimator with the ACDT)

Photovoltaics

Technology, Construction, Limitations

This discussion does not address the surface chemistry/quantum physics of photovoltaic materials, a subject beyond the scope of this report, but rather describes the Advanced Photovoltaic Systems (APS) technology and then briefly lists other similar photovoltaic technologies which have been used for utility-scale power production.

The APS photovoltaic product is a flat-plate cell using a thin-film amorphous silicon technology. There are many other photovoltaic technologies in the industry - single-crystal, polycrystalline - as well as enhancements such as solar concentration and tracking. The APS module is fabricated from two layers of 1/8" thick glass in [roughly] the following fashion: tin oxide is deposited onto the face of one of the panes via a plasma arc process; the tin layer is then scribed with a laser; three layers of silicon are then deposited on the tin oxide layer, also using the plasma arc process; and then a layer of aluminum is sputtered onto the silicon layers (the total thickness of the aggregate film is about 1.5 microns); this pane of glass is then laminated onto the other pane of glass, thin-film inside, using ethyl vinyl acetate (EVA) as the laminating material. The APS module has a power conversion efficiency rated at approximately 5.6%[1].

The module's power conversion efficiency varies with two parameters: the number of hours the panel has been irradiated; and the temperature of the photovoltaic junction. The first degradation, a function of light soaking known as the Staebler/Wronski Effect, is a well-documented and measured degradation peculiar to thin-film photovoltaic technologies, but the industry does not, as yet, know the precise cause[2]. The degradation does seem to stabilize or saturate with time, which can be seen by reviewing figures 4 and 5, following. APS accounts for this degradation by rating their modules' efficiencies *at the third year* of light soaking. The second degradation, a function of junction temperature, is typical for all photovoltaic technologies, and the APS modules have temperature coefficients equal to 0.08% per degree C for cell current, and -0.35% per degree C for cell voltage, yielding an efficiency degradation of approximately 0.0028% per degree C higher than 25°C junction temperature.

A concern with using the APS materials is that another firm, Solarex[3], has a lawsuit pending against APS. We are not equipped to evaluate the nature nor the validity of the lawsuit.

Another company - United Solar Systems Corporation - produces photovoltaic cells using thin-film technology, but on a rigid galvanized steel or a flexible polyester ribbon backing. Their maximum physical dimensions are approximately 1' x 4', and their efficiencies appear to be about 5.9%. These cells may be useful in other photovoltaic/building component integrations.

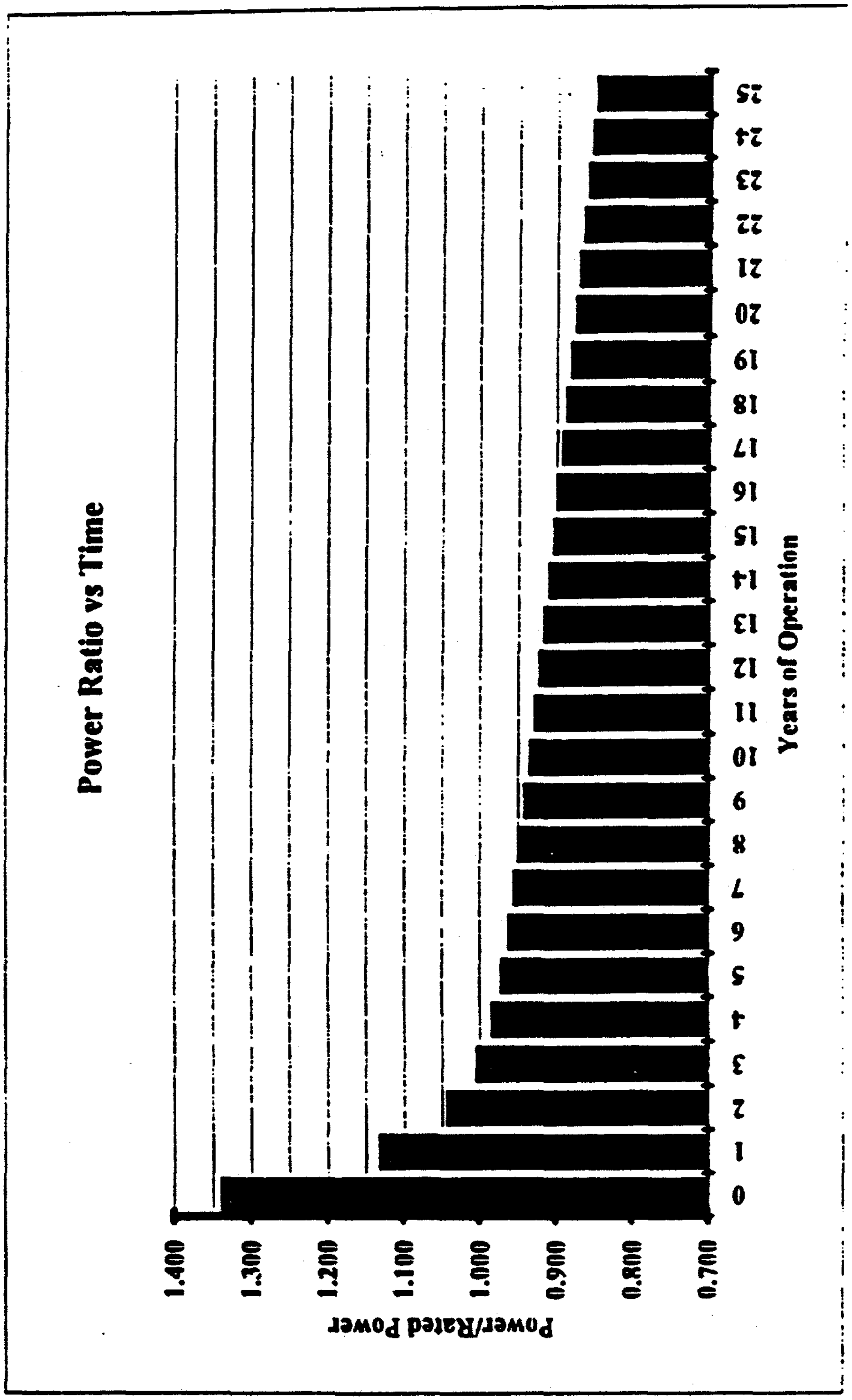
---

[1] PV conversion efficiencies are measured in standardized tests, with irradiances equal to 1000 W/m^2 and module temperatures equal to 25°C, per ASTM E892 & E1036

[2] from a discussion with Chris Wronski, listed appendix 2

[3] Solarex also makes amorphous silicon photovoltaic cells

MODULE1.XLS



0	1.334
1	1.128
2	1.040
3	1.000
4	0.980
5	0.967
6	0.958
7	0.951
8	0.944
9	0.937
10	0.930
11	0.924
12	0.918
13	0.912
14	0.906
15	0.900
16	0.894
17	0.888
18	0.883
19	0.877
20	0.871
21	0.866
22	0.861
23	0.855
24	0.850
25	0.845

Figure 4: Photovoltaic Cell Efficiency vs. Age

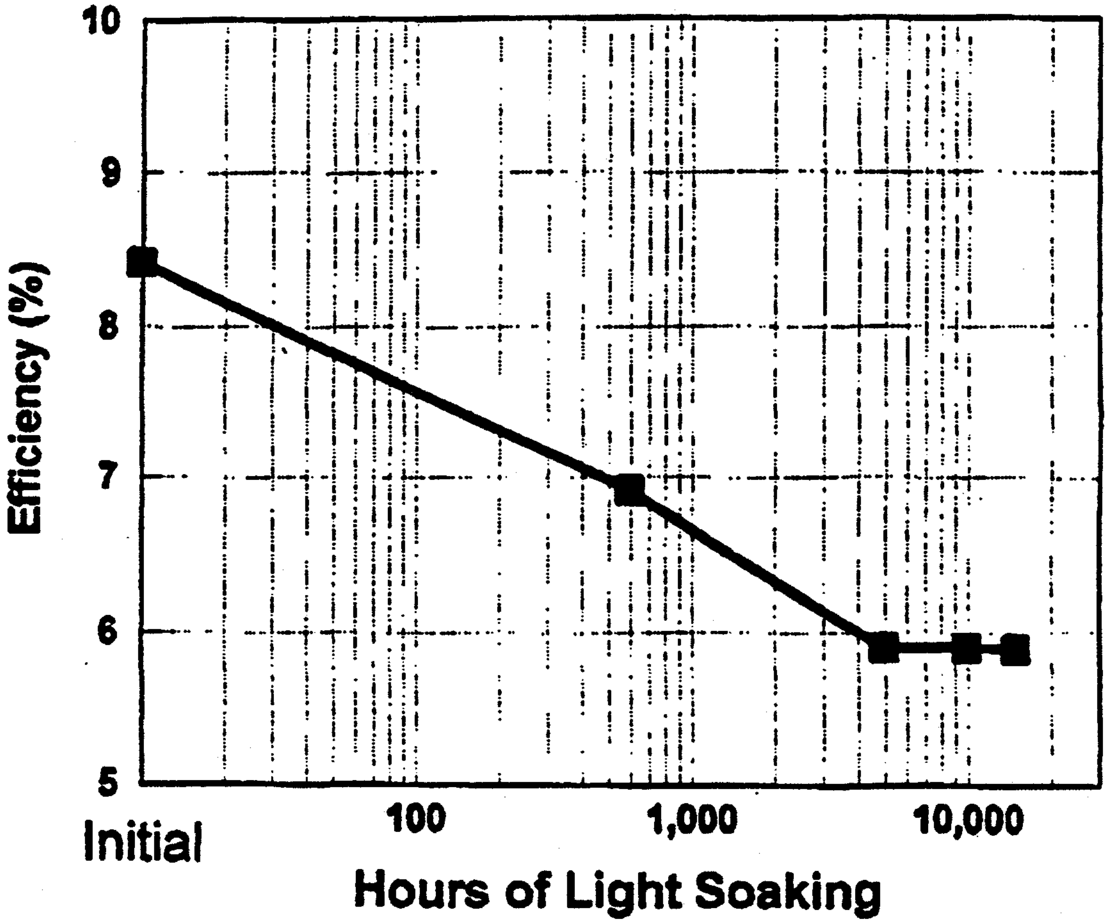


Figure 5: Photovoltaic Cell Efficiency vs. Hours of Light Soaking

Hal Post of Sandia Laboratories, as well as Brian Farmer, of PG&E pose an interesting question: since we are spending so much money (with the long-span structure, the glass cladding or pressure plate systems), why not use a photovoltaic technology - single crystal or polycrystalline, for examples - which could perhaps raise our conversion efficiency to as much as 10%? Pursuing this question is not in the scope of this report; we merely point to Siemens Solar's single-crystal silicon, enhanced by one-axis passive tracking, as the only PV material which could fit the utility-grade production requirement[4], but its passive tracking enhancement cannot be included in a photovoltaic array to be integrated with building components.

Optimal Tilt and Tilt+Bearing Sensitivity Discussion

This discussion develops the optimum tilt angle for collection (see below), as well as the sensitivity of generation capacity to variations of tilt angle from the optimum. This discussion should not limit the roof's development; indeed, it shows that the roof geometry shall have minimal effect on its power generation. The intent of the optimal tilt angle exercise is not the typical one used by solar engineers: as the project is funded in part by Georgia Power, we are much more interested in limiting the use of Georgia Power's combustion turbines during the (utility) system's peak than in producing the greatest energy over the entire year. Thusly, we address a window of afternoon hours, from 12:00 noon to 8:00 PM, June 1 through September 30. These hours are drawn from the [attached, see figures 6 & 7] charts indicating the power generated on a system peak demand day - August 11, 1992 (peaked out at 307163 MWH). The upper limit of the hour window is, of course, less relevant for PV power generation, but we include it for completeness. The results of our limited window indeed fall outside the rules-of-thumb used by solar engineers, which generally pay more attention to winter months; we do not follow the **latitude** or the **latitude less fifteen** rules, by any means.

We first used incident direct beam radiation and standard geometrical relationships to find the optimum tilt for the PV array. The earth's atmospheric transmittance was addressed, using Hottel's standard atmosphere transmittance with 23 km visibility equations (1976). This simple model indicates that the best angle would be 16 degrees up from the horizontal (with a surface azimuth 5 degrees west of south). The sensitivity of incident direct beam radiation to variations of tilt is minimal (within 1.5% of peak) while the tilt is within 7 to 26 degrees up from horizontal. This model does not take into account the varying reflectivity property of glasses, nor the varying insolation due to cloudiness typical in Atlanta.

APS explored the same question, and provided JND Sterling information indicating average daily insolations for various tilt angles, using monthly data. APS' information shows that the best tilt angles for peak insolation over the course of a day are from 5 to 10 degrees above horizontal, with little (1.5% or less) sensitivity to changes in tilt in the interval between 0 and 20 degrees. APS' results also indicate that the bearing [azimuth] of the surface had very negligible impact on the surfaces' insolation during the summer months.

---

[4] the 1992 PVUSA Annual Report lists two Siemens installations totaling about 675 kW ac power in place; another installation uses Mobil Solar cells, and Mobile has recently ceased its photovoltaic activities

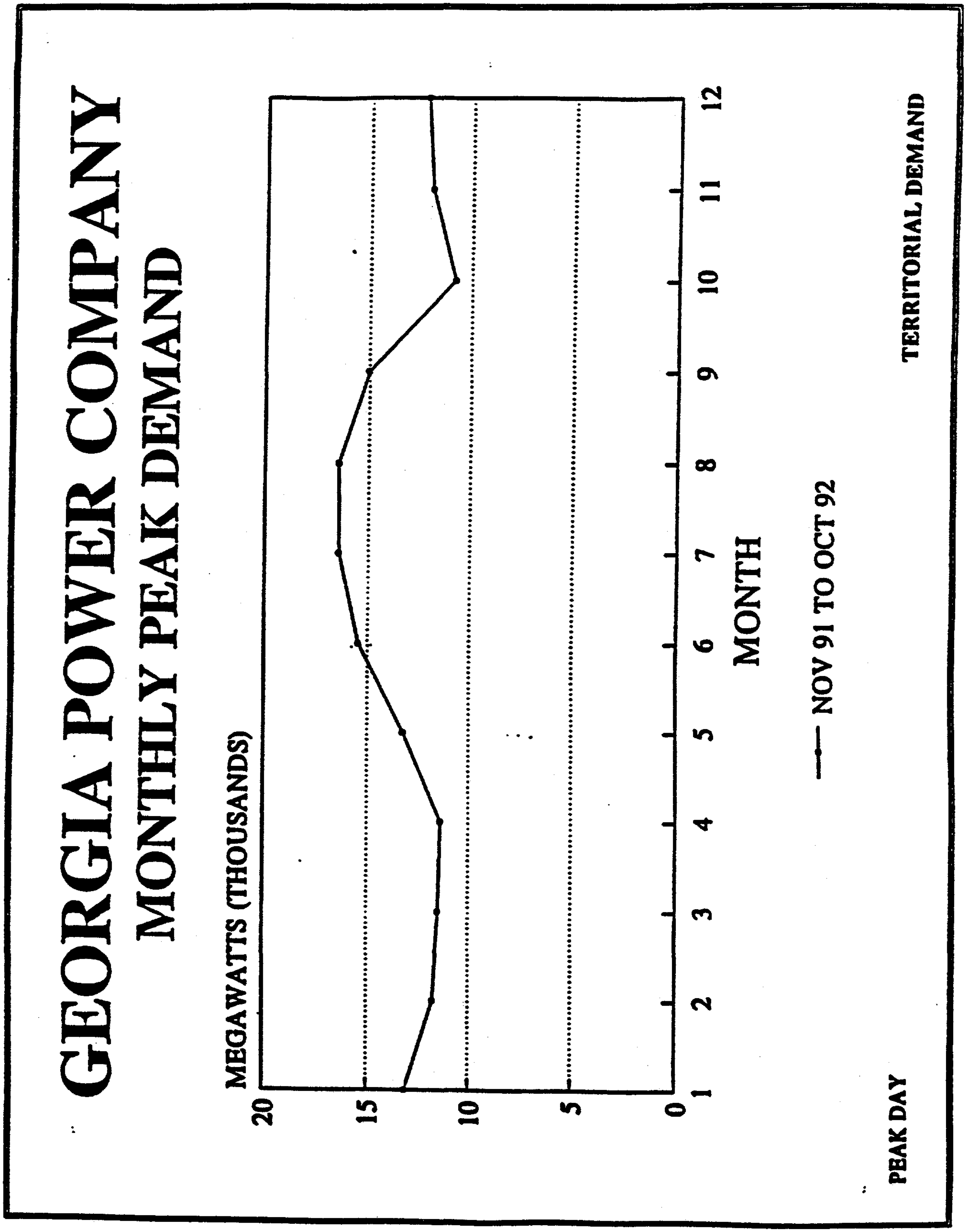


Figure 6: Georgia Power Company Monthly Peak Demand

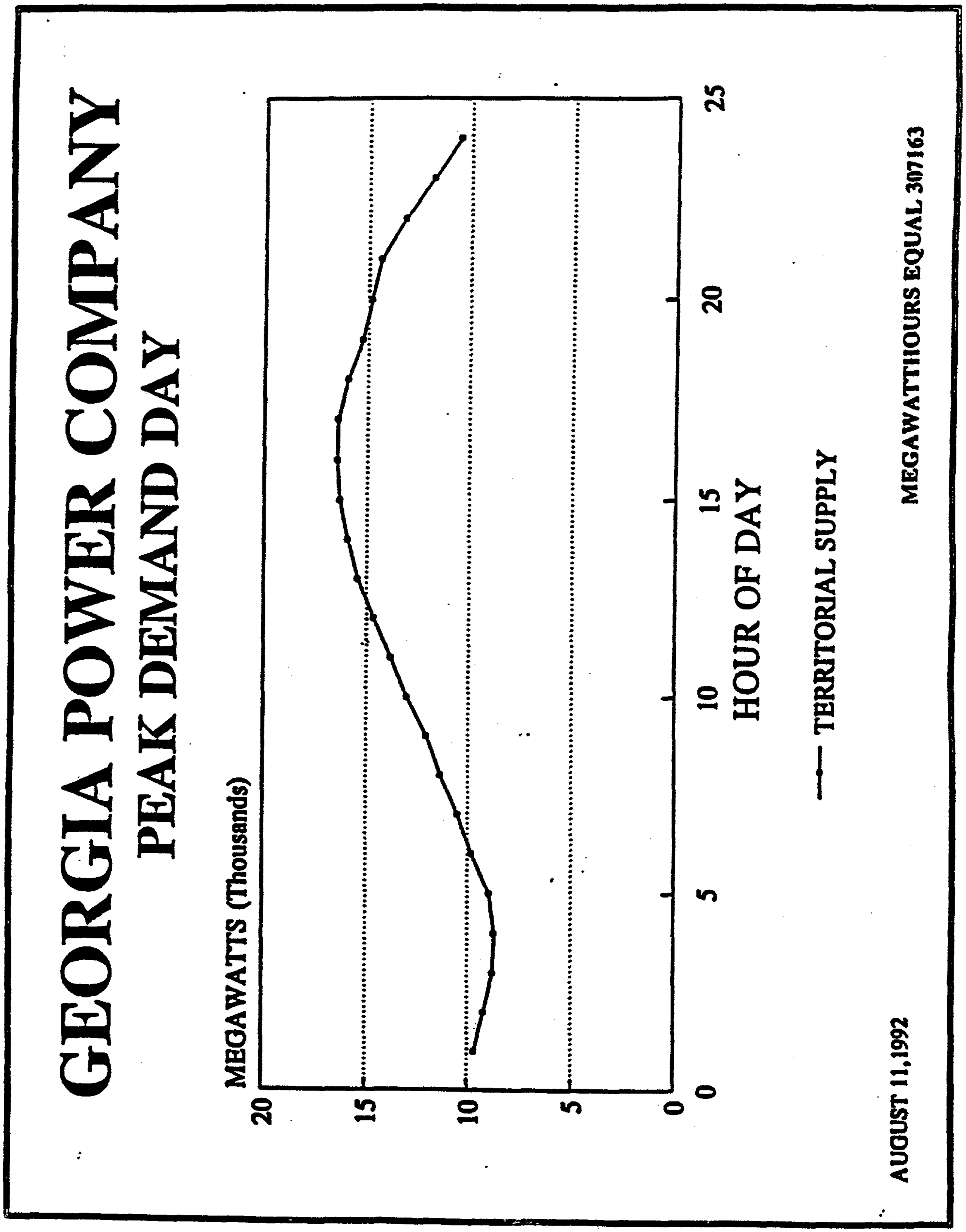


Figure 7: Georgia Power Company Peak Demand Day

JND Sterling also applied the ASL ESP+[5] model, using Atlanta's Typical Meteorological Year (TMY) weather data. The insolation was verified against published data from the National Climatic Center in Asheville, NC. This data describes, in addition to the typical geometrical relationships, the cloud cover one might typically expect in the Atlanta area. The model took into account the variable reflectivity of the outer pane of glass, and was filtered to only address the daylit hours after 12:00 noon, during Georgia Power's summer season. The results indicate that a collector tilt equal to 8 degrees above the horizontal would perform best for our window of use, and that the sensitivity of insolation to the collector's tilt is minimal (within 1.5%) while within the 0 to 17 degrees tilt interval.

Architectural considerations would prefer a tilt of about 10 degrees up from the horizontal, for rain shedding.

Electrical Interface Discussion

A self-evident, but sometimes forgotten, aspect of photovoltaics is that whenever there is sunlight incident on the panels, they are developing voltage and, if allowed to, are producing power. In order to produce any useful amount of power at a reasonable component cost one must connect cells in series to develop a large voltage difference. These conditions require that treatment and service of the dc power collection net be viewed from a utility perspective. The personnel working on the collection net must be trained in safe work practices with hot conductors. Likewise, the glaziers installing the PV system must be trained in handling the cells properly. The wiring connections between the cells in mounted series[6] must be rated for disconnection while loaded. The cabling shall be grounded, per National Electric Code (NEC), and shall run in watertight areas/conduits to the inverter.

The inverter component in the PV system requires, by many accounts[7], the most scrutiny and design effort, as it causes most of the short-term generation outages in systems throughout the country. These generation outages seem to run counter to the experiences of the uninterruptible power supply (UPS) industry. One account[8] for this contrast is that the inverter efficiencies required by the photovoltaic industry (90%+) are much higher than those used by the UPS industry (~75%). The inverter component is, by far the single most expensive piece of equipment in a PV system, and is also responsible for the quality of the ac power generated by the installation. As such, specification of inverter protection and operating parameters is most important in a PV design. PVUSA has developed requirements for inverter, PV array, and utility safety and protection which seem to be most complete; indeed, many of these requirements parallel those given in Georgia Power Company's Bulletin 51, which describes interconnection requirements for customer-owned generation (see appendix 3).

The Natatorium's photovoltaic array is classified by the [GPC] Bulletin 51 as a small generator, interconnected with the utility at the Natatorium's distribution system. The power flow may be, until further evaluation of the Natatorium is done, either one- or two-way. The appropriate protection requirements are shown graphically by Figures 7 and 8 in the Bulletin. The customer

---

[5] an Abacus Simulations, Ltd. computer program; used as the standard in the EC countries

[6] connections of the "pigtails" on the back of the PV cells

[7] this sentiment was voiced by Brain Farmer, PG&E; Kenneth Ragsdale, Austin Electric Department; and Hal Post, Sandia Laboratories

[8] Hal Post, Sandia Laboratories

side of the interconnection include an accessible and lockable disconnect (also required by the NEC as well as other standards), with a caveat that voltage checking may be required on the customer side. This caveat, as well as the following Bulletin 51 requirements, are parallel to requirements of PVUSA for inverters: the voltage may not vary 6% above or below the service voltage (protection by automatic disconnect); voltage flicker shall not be greater than 2% at the facility's transformer primary side; the frequency shall not vary outside 59.5hz - 60.5hz (protection shall be automatic, and within 0.2 seconds); the power factor must be greater than 0.85 (an irrelevant point, as inverters can produce any power factor - including unity - that the operator requires); and harmonics shall not exceed 5% total current distortion, 5% total voltage distortion, and also not exceed individual harmonic order limitations. All of these requirements may be easily met by a number of commercially available inverters.

Roof Design Development

Aesthetic and Programmatic Criteria

Aesthetic Features

The Aquatic Center Design Team (ACDT) has identified the roof form of the Aquatic Center as having tremendous aesthetic impact to the character of the project, both during the 1996 Olympics and the Georgia Tech post-Olympic Campus. The Aquatic Center's roof form and associated support structure will become the dominant feature of the Callaway Student Athletic Center. Preliminary investigations have led to the selection of the curved vaulted roof form as an appropriate image expression for the Aquatic Center. Photovoltaic panels would be used to define the vault by means of segmented panels. ACDT feels the reflective "slick" appearance of the PV panels coupled with the curved form is an appropriate and dramatic visual statement. The aluminum framing employed to restrain the PV panel roof "skin" would be manipulated by ACDT in order to achieve a "ribbed" vault effect giving scale and order to the expansive roof area. The roof underside will be expressed in the form of exposed steel trusses placed 22 feet on center. All photovoltaic related wiring will be collected and organized in dedicated raceways, so as not to detract from the structurally imposed order visible to the Aquatic Center spectators seated below (see figures 8, 9 & 10, following).

Programmatic Criteria

The limits of the current state of photovoltaic technology have been considered by ACDT in the roof integration detailing proposed for the Aquatic Center. Advanced Photovoltaic Systems (APS) indicates the current maximum photovoltaic panel size to be 5 feet x 2½ feet. Thus, the PV panel size limitation becomes the module upon which the Aquatic Center Roof panel framing is based (see figure 8, following). ACDT considered the possibility of grouping 4 PV panels as part of a composite glass panel, resulting in a 5 foot x 10 foot framing module. Waterproofing of the Aquatic Center permanent roof is a primary goal of ACDT's architectural detailing. Two options to waterproofing with PV. integration have been identified (see Architectural Detailing Design Development: Weatherproofing, below, for options).

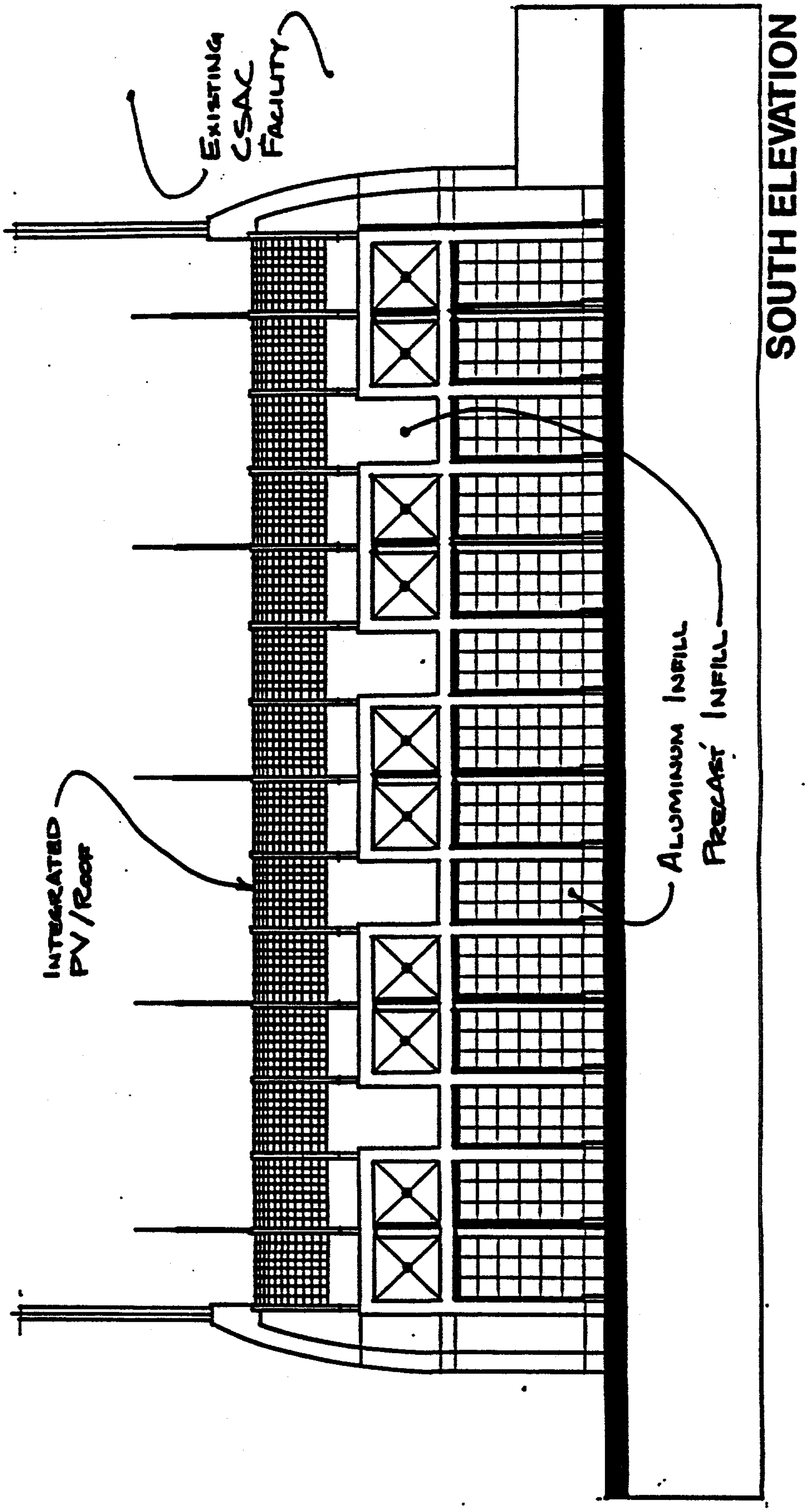


Figure 8: South Elevation

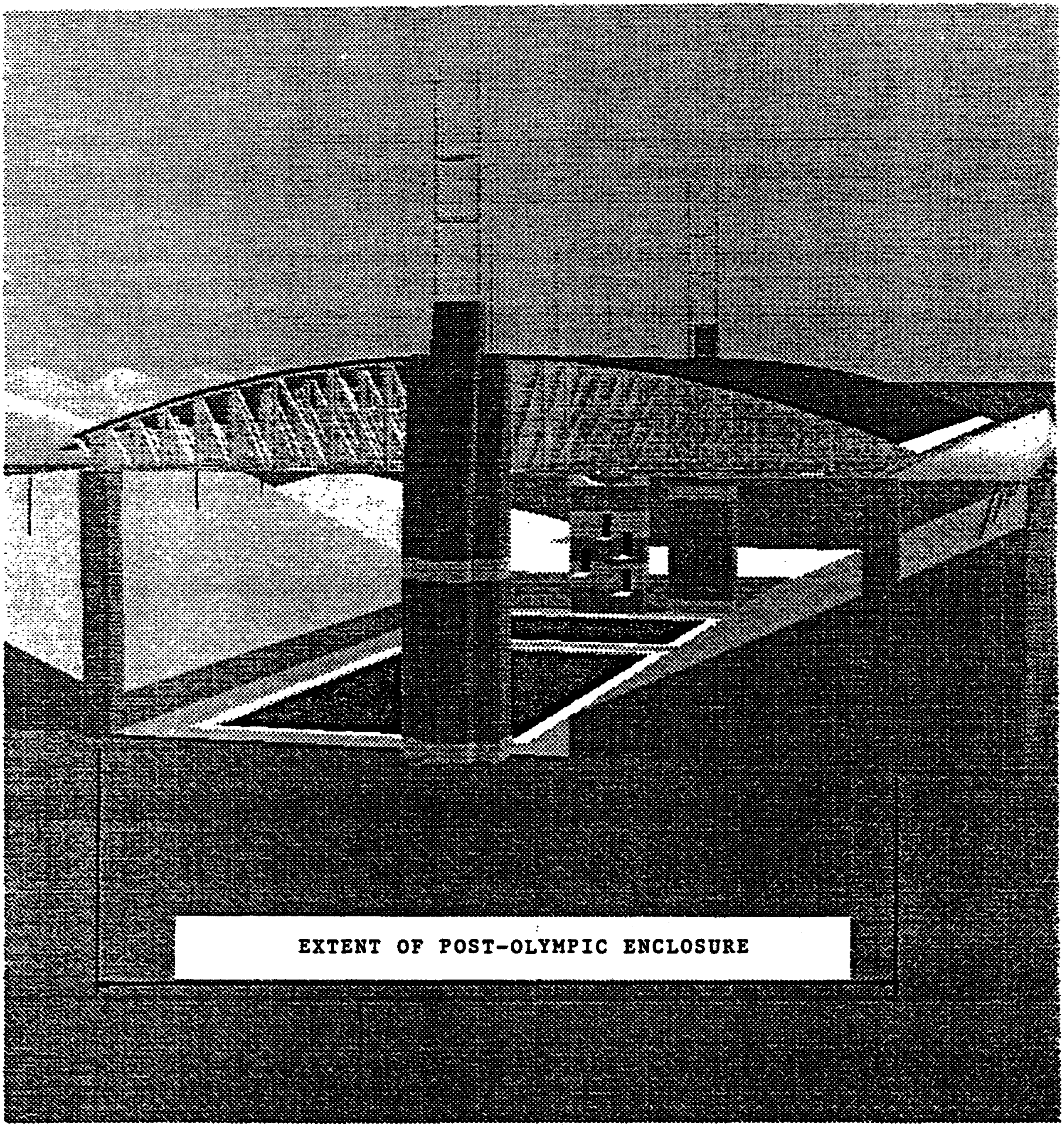


Figure 9: East View, Natation Venue, Olympic Use

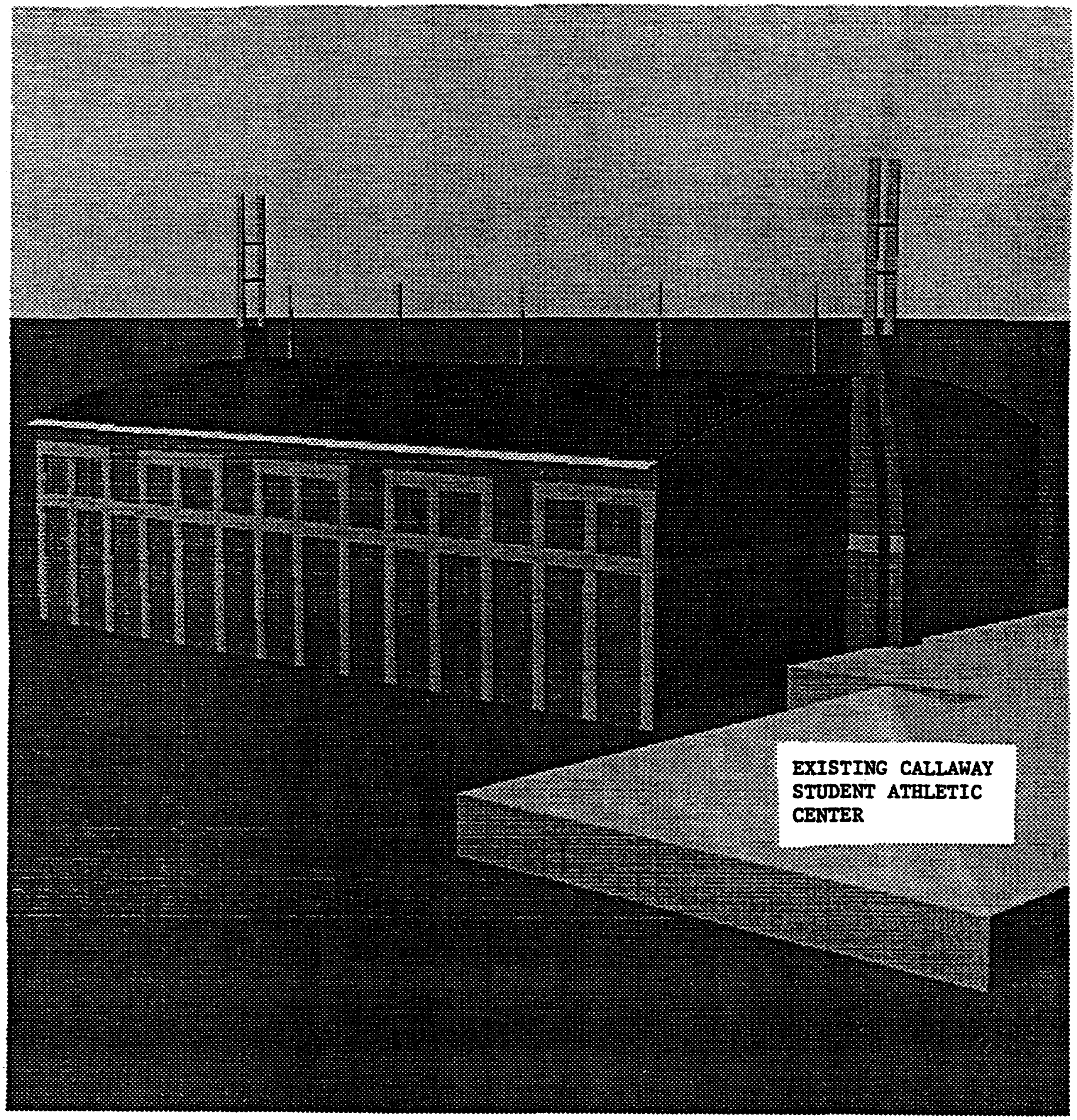


Figure 10: South View, Georgia Institute of Technology Natatorium

JND Sterling, in conjunction with ACDT, has identified additional criteria to which the roof should be designed. They include:

* The roof shall be entirely opaque (no daylighting shall be allowed) for the following two reasons: it interferes with television cameras; and it is dangerous to have glare incident on divers.
* The roof shall be reasonably well-insulated, and there shall be absolutely no "cold-connections" in the systems, to prevent condensation of the warm humid indoor air of the enclosed Natatorium on any skin surfaces. Condensation of the indoor air on ferrous building materials will often corrode them, as the indoor air is rich in chlorine outgassed from the pool water and condensation will render hydrochloric acid on the building materials.
* The roof shall not contribute to the already bad internal acoustics inherent in Natatoriums. Non-parallel surfaces and field-breaking trusses are required to reduce the roof's contributions.
* The roof's PV sealing compounds shall be able to withstand long-term weathering and UV ray incidence without degradation or color alteration.
* The roof shall be fitted with lightning rods, to protect the expensive PV array.
* The roof shall be fitted with some in-place means to wash and service the PV panels, much like window-washing equipment carried by tracks.

Expected Enclosed Building HVAC Electrical Loads' Criteria

The photovoltaic/roof integration will be transparent to the Natatorium's mechanical and electrical loads, with the exception of the facility's main switchboard: it will have an additional power feed into it (480V, 600A solid-state circuit breaker). The Natatorium's program requires that the roof be opaque and well-insulated[9], so the cells' limited light transmittance will be blocked at the roof, allowing for no solar load into the facility. As a courtesy to the Board of Regents, JND Sterling has estimated the Natatorium's block mechanical and electrical loads, attached in appendix 4. JND Sterling is not, however, the engineer for the ACDT, and cannot vouch for the calculations' appropriateness to the design; we worked only with a conceptual massing of the facility, and assumed many loads and system treatments. Nonetheless, we found:

* the Natatorium block cooling load to be 438 tons;
* the Natatorium block heating load to be 5077 mbh; and
* the Natatorium block electrical load to be 1958 kVA, necessitating a building voltage at 480Y/277, a 2000 kVA transformer, and a 2500 A fused Service Entrance Switch

This above transformer - 2000 kVA - was sized using the National Electric Code, as it is a customer-installed device. Transformers sized using NEC methods are typically well oversized.

---

[9] see Aesthetic & Programmatic Criteria, above

Expected Power Generation

Using an ASL ESP+[10] model of the conceptual design roof by the ACDT, we find the energy generated *at the Natatorium's main switch gear*[11] by the PV array to be as follows[12]:

Array Power Output during GPC system peak (8-11-92)		**Array Peak Power Output (6-8)**	
First Year	311 kW	First Year	336 kW
Third Year	276 kW	Third Year	298 kW
Tenth Year	257 kW	Tenth Year	277 kW
Eighteenth Year	244 kW	Eighteenth Year	263 kW

Monthly Energy Generated, First Year of Operation

January	24200 kWh	July	67500 kWh
February	29400 kWh	August	63600 kWh
March	47100 kWh	September	47300 kWh
April	58100 kWh	October	42200 kWh
May	70900 kWh	November	28500 kWh
June	67000 kWh	December	23000 kWh
Year Total	568600 kWh		

Monthly Energy Generated, Third Year of Operation

January	21400 kWh	July	59800 kWh
February	26000 kWh	August	56400 kWh
March	41800 kWh	September	41900 kWh
April	51500 kWh	October	37400 kWh
May	62800 kWh	November	25200 kWh
June	59400 kWh	December	20400 kWh
Year Total	504100 kWh		

Monthly Energy Generated, Tenth Year of Operation

January	19900 kWh	July	55600 kWh
February	24200 kWh	August	52500 kWh
March	38800 kWh	September	39000 kWh
April	47900 kWh	October	34800 kWh
May	58400 kWh	November	23500 kWh
June	55300 kWh	December	18900 kWh
Year Total	468800 kWh		

---

[10] see Optimal Tilt Criteria discussion, above

[11] these calculations were made using 0.0652 conversion efficiency *at the amorphous silicone surface,* an inverter/transformer/filter efficiency of approximately 92%, and a 12% opaque/dead area.

[12] the power output degrades due to the Staebler/Wronski Effect; see Photovoltaics discussion, above

Monthly Energy Generated, Eighteenth Year of Operation

January	18900 kWh	July	52800 kWh
February	23000 kWh	August	49800 kWh
March	36900 kWh	September	37000 kWh
April	45500 kWh	October	33000 kWh
May	55500 kWh	November	22300 kWh
June	52500 kWh	December	18000 kWh
Year Total	445100 kWh		

Electrical Design Development Criteria

The Natatorium roof's architectural conceptual design provides for fourteen 230' long x 20' wide (approximate) sections on which photovoltaics may be placed. Each of these sections is composed of 8 PV cells wired in series (we call them *rows*), and 46 of these series-mounted rows mounted in parallel. Using the APS 65W module as a basis for this discussion, each row develops a voltage difference of 346Vdc (452V open-circuit) and a current equal to 1.51Adc (2.05A short-circuit). The 46 rows in parallel provide 69A current. Thus, each of the fourteen sections produce 346Vdc and 69Adc. Please see the figure 11, following.

The industry's inverters of choice[13] appear to be those manufactured by Omnion, which use a three-wire (+,N,-) dc wiring net. The roof has seven *panels*, each composed of two adjacent sections: one section providing + to N voltage, and the other section providing N to - voltage. The panels' fused switches, varistors and blocking diodes are placed, in accordance with NFPA 70, on the + and - sides of the panels. Wiring downstream of the switches/diodes is spliced (in weatherproof j-boxes) 5KV copper CLP shielded cable. Each panels' three cables is carried back to the inverters. The inverters should be two Omnion[14] 150kW inverters manifolded in parallel, for redundancy. The Omnion inverter is a self-commutated pulse-width modulation inverter built from gate bi-polar transistors, which appear to be particularly sturdy. The inverters shall be provided with maximum-power-tracking circuitry, dc ripple-voltage filters, loaded break dc disconnects (visible, logical and lockable), panel disconnects for cases of temporary solar enhancement transients, ac harmonics filters, motor-driven draw-out type ac circuit breakers (visible, logical and lockable), a dc-injection isolation transformer, and all protection features to for it, the photovoltaic array and the utility in the event of an inverter failure or from parameters beyond the inverter's safe operating range.

The inverters, their filters and isolation transformer will provide the GIT power grid with clean power, well within the [GPC] Bulletin 51 constraints. Protection of personnel and Natatorium equipment shall be through a circuit breaker at the ac-side of the dc-injection isolation transformer, a visible logical fused switch near the inverter/isolation transformer, and a solid-state circuit breaker mounted in the Natatorium's main switchboard. Islanding (unexpected and dangerous customer powering of the utility grid during service) should not be a problem in this small of a generation system.

---

[13] described as such in many interviews

[14] Abacus also makes inverters, using similar technology, but their largest size seems to be 100kVA, so the facility would require three inverters.

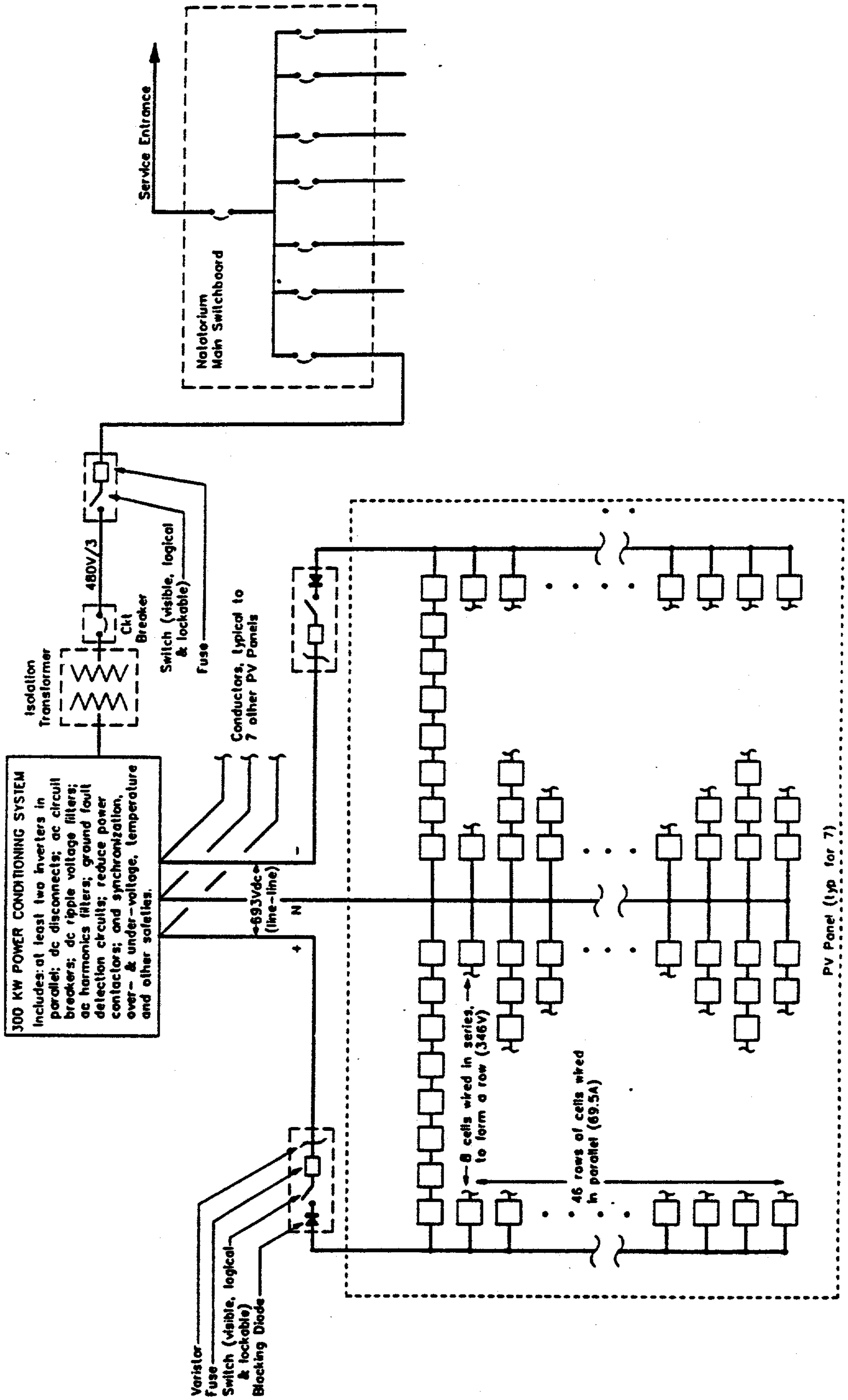


Figure 11: PV Array Conceptual Electrical Design

PV Array Conceptual Electrical Design
JND STERLING

Structural Design Development

Scheme One (see figure 12, following)

The roof structure is steel framed with metal deck, purlins and trusses. The rolled purlins are about 6'-0" on center. They will weigh 1.5 psf of roof area. These purlins support a metal roof deck which is a wide rib 20 gauge B deck. The purlins span between curved top chord trusses at 22'-0" centers. These trusses span 100'- 0" from a center box truss to a spandrel truss. These 100'-0" trusses will weigh about 62 plf. The center box truss will be composed of two trusses about 10'-0" apart which will be connected together. Each truss will weigh 575 plf including the connecting members. The spandrel trusses on each of the long sides of the building will weigh about 850 plf.

Connections and bracing for the steel roof structure are estimated at 15 per cent of the gross steel weight of the roof.

The vertical support for the center box truss is proposed as a steel vertical box type tower that will be configured to the architect's profile. This vertical element is estimated to weigh 600 plf of height. It will require (20) 100 ton auger cast piles for foundations. On each end of the spandrel trusses the support will be large 78 inch square concrete columns. Each of these columns utilize (10) 1 ton auger cast piles.

Scheme Two (see figure 13, following)

The roof under this scheme will also be steel framed with purlins and trusses. The purlins and deck will be the same as the other scheme. The roof will be framed with curved top trusses at 22'-0" on center. They will be supported on concrete 48 inch concrete columns on one end and by a box truss 55'-0" from the other end of the truss. This curved top truss must cantilever 55'-0". These curved top trusses weigh about 70 plf. The box truss supporting the cantilever end of the curved top trusses is constructed the same as the center box truss of the other scheme. Each truss of the box truss will weigh in the range of 900 plf including the connecting members. There are no spandrel trusses in this scheme. Bracing and connections should be the same as in Scheme One.

The box truss that supports the curved trusses will be supported on a vertical steel box type tower structure. Again this structure will be configured to match the architect's requirements. The current proposal suggests the integration of the diving tower structure as part of the support column at the east side of the roof. The support column is estimated to weigh 800 plf of vertical height. It will require (24) 100 ton auger cast piles. The 48 inch concrete columns will require (3) 100 ton auger cast piles.

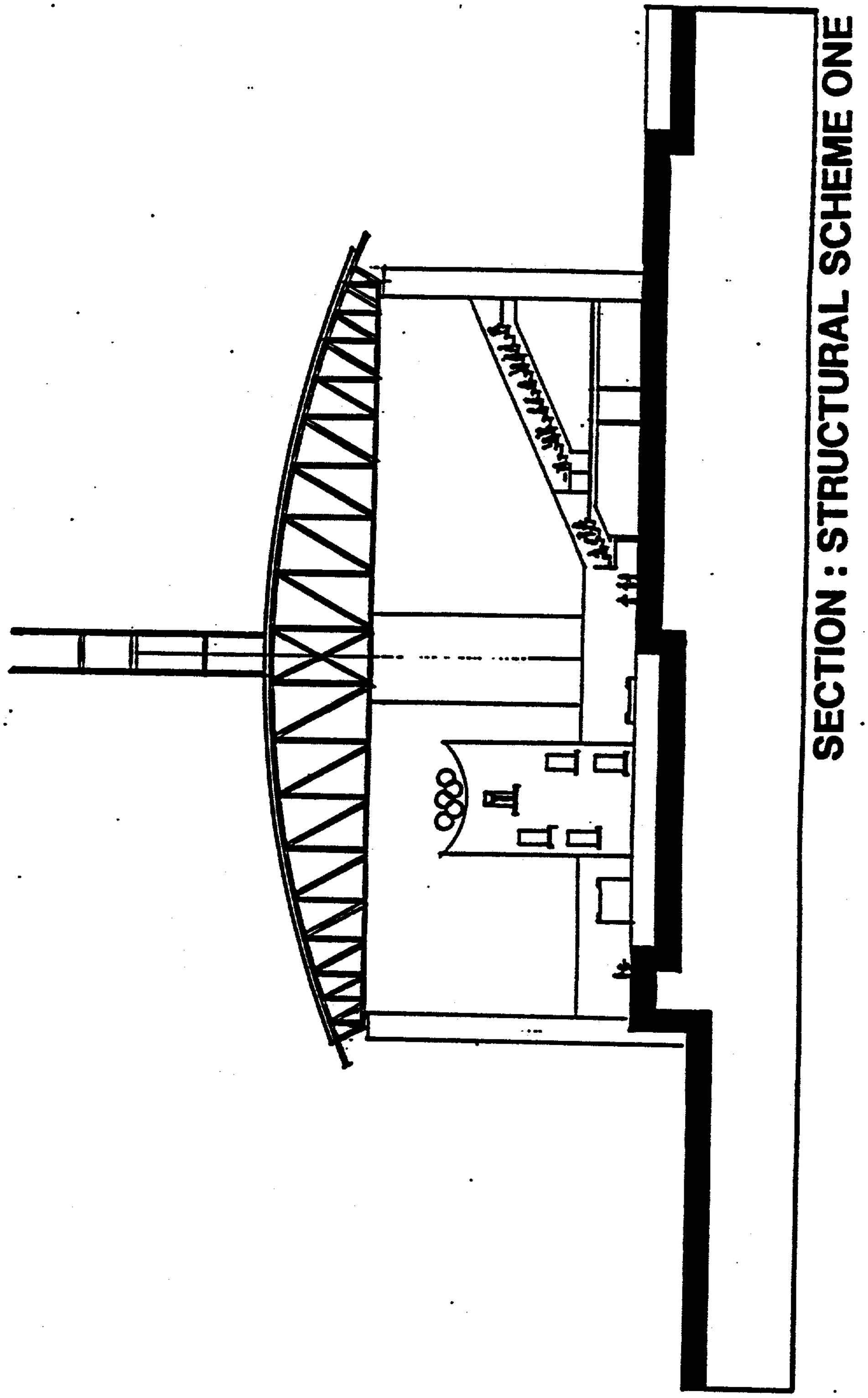


Figure 12: Section, Structural Scheme One

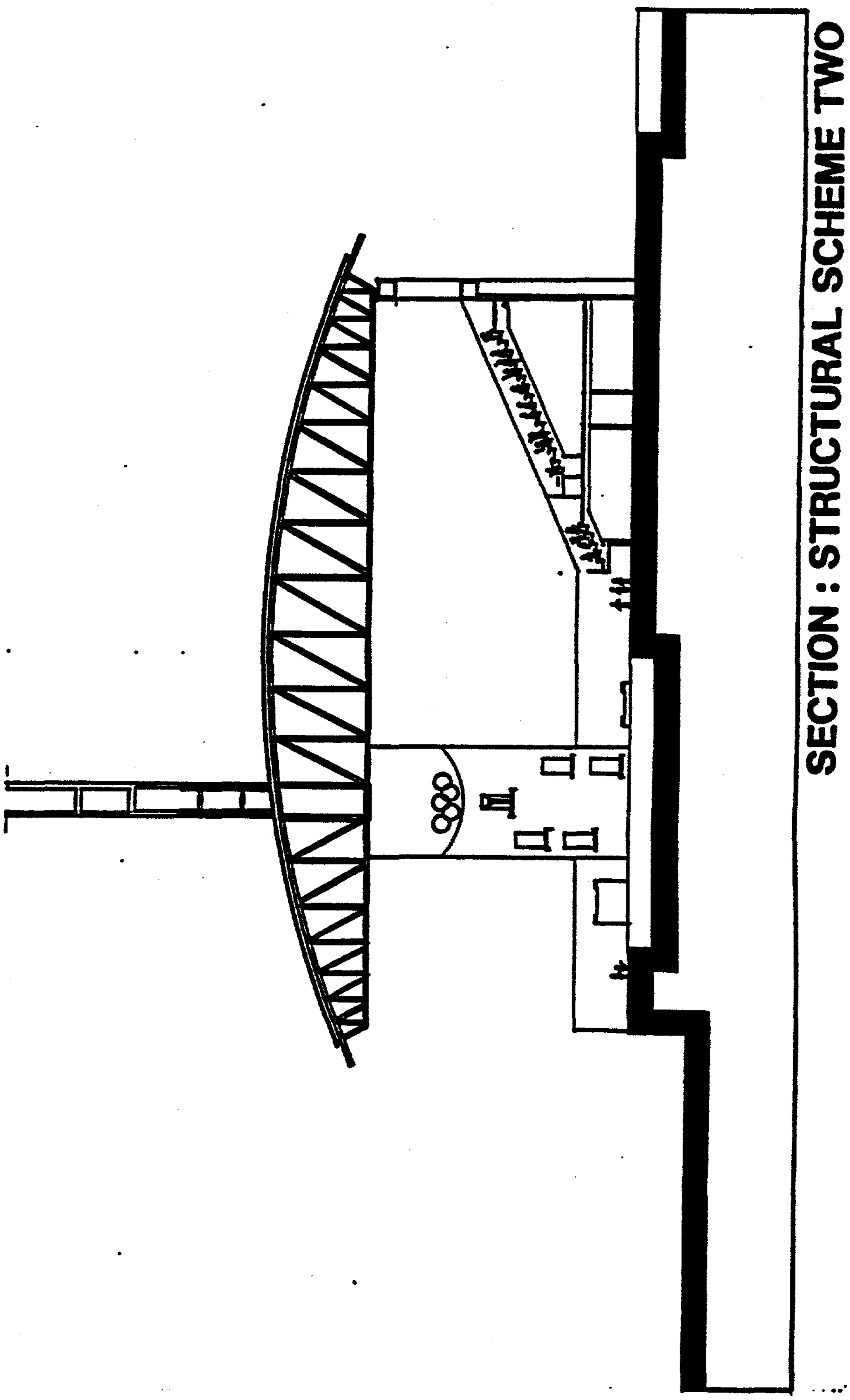


Figure 13: Section, Structural Scheme Two

Architectural Detailing Design Development: Weatherproofing

Summary of Objective

ACDT and JND Sterling have stressed weatherproofing as the prime objective of any architectural detailing related to the photovoltaic roof system. Two methods are proposed by which photovoltaic integration may occur with no compromise to the integrity of roof as a weather skin:

1. Option A considers the inclusion of photovoltaic panels in a PPG Industries, Inc. cladding system with an independent waterproof roof membrane below the PV. panel/PPG assembly.
2. Option B considers the inclusion of photovoltaic panels in a waterproof insulated glass panel skylight system proposed by Super Sky Products, Inc.

The significant difference between the two options is the inclusion of photovoltaic panels in the waterproof skin proposed in option B.

Option A (see figure 14, following)

Option A proposes to adapt the standard PPG EFG-601 glazing system by using a photovoltaic panel as the outer glass light. A silicone edge seal would encapsulate the panel at all four sides. Support framing for the system would correspond to the 5 foot x 2½ foot module dictated by PV panel fabrications limits. A continuous layer of waterproof roofing membrane would be placed directly below the glazing and act as the primary water barrier. The next layer in the roof system would have rigid insulation on top of 20 gauge metal deck supported by purlins spaced 6 feet on center above the structural long span truss. The roof assembly described above would allow the PV panels to function as a secondary barrier to water penetration protecting the waterproof membrane below. Costs for Option A are identified in appendix 5 as Skin Scheme - PPG on Metal Deck.

Option B (see figure 15 following)

Option B proposes to use PV panels as the outer glass light of a Super Sky skylight system. Super Sky would group a series of 4 PV panels within a single skylight panel with a pressure plate and zipper gasket system utilizing a 5 foot x 10 foot module. The PV panels would primarily be self supporting with some minor bracing at PV panel to PV panel joints. Major skylight framing members would occur on the 5 foot x 10 foot module. High performance silicone structural sealant would be used at all panel joints. The glass skylight skin would function as the primary waterproof barrier, supported by a metal support structure of approximately 8 inch x 2 inch members resting on purlins. Costs for Option B are identified in appendix 5 as Skin Scheme - Super Sky (panel approach). In the appendix, costs for Super Sky framing in the individual PV panels is also included, for comparison; this scheme is labeled Skin Scheme - Super Sky (stick approach).

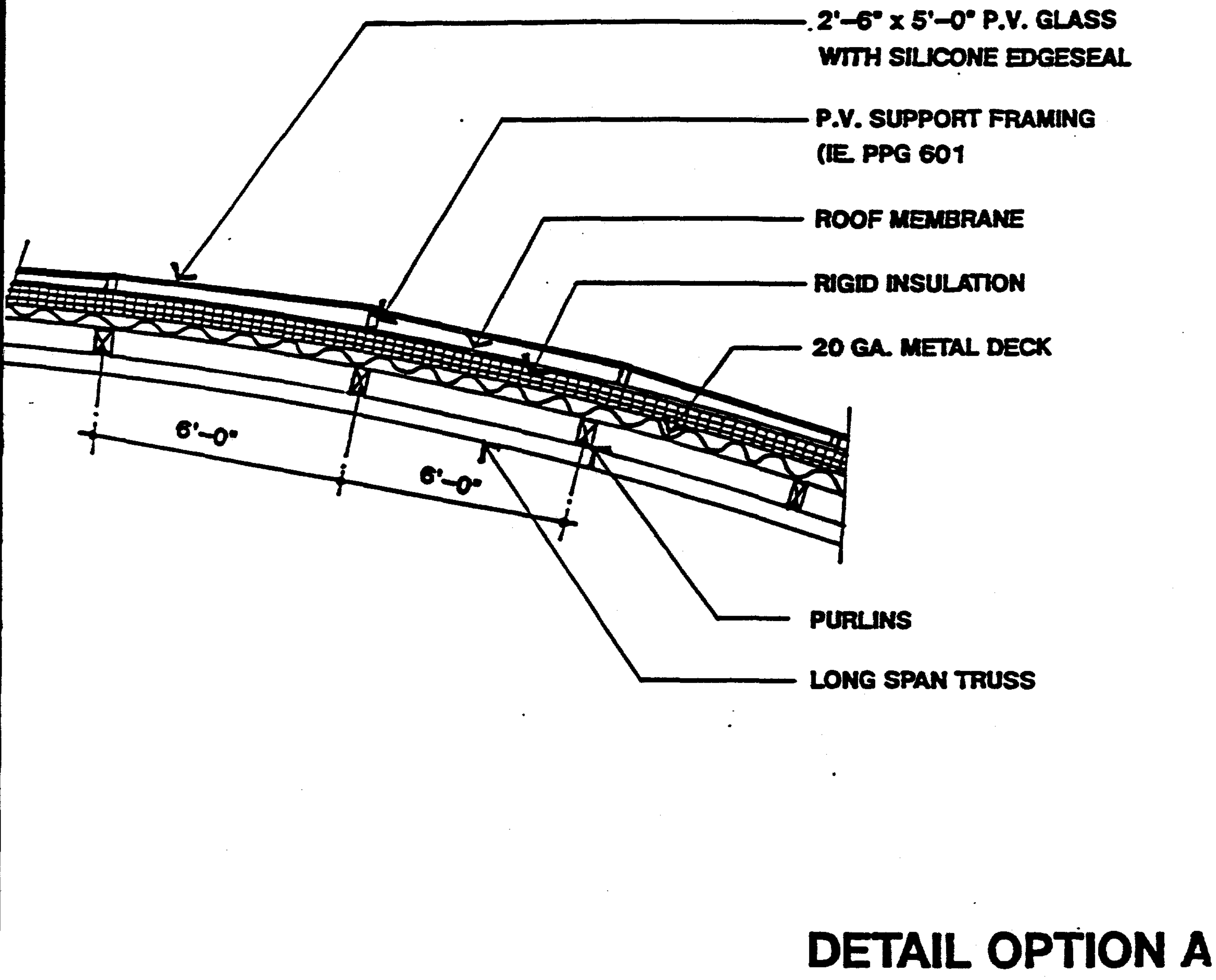
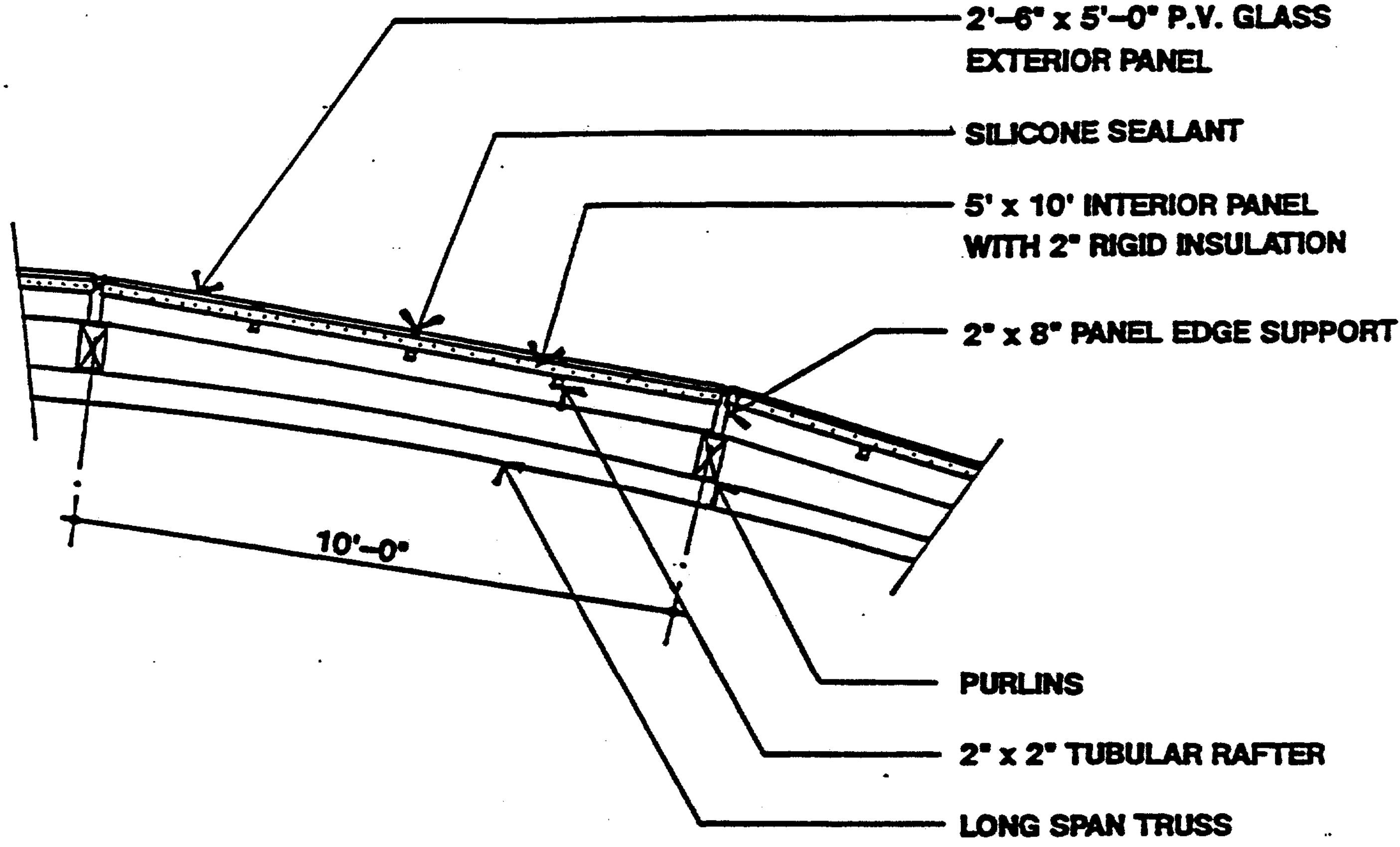


Figure 14: Detail, Option A



DETAIL OPTION B

Figure 15: Detail, Option B

Expected Budget for the Proposed Roof

The proposed photovoltaic/roof integration should cost approximately $5.1 to $6.4 million[15]. These sums' components are broken up as shown below:

* Skin, including PV cells, but not their dc wiring[16]:	$2,409,040[17] to $3,610,075
* Gross Structure, composed of long-span trusses[18]:	$2,178,232 to $2,262,474
* Electrical Interface, which includes the inverter and isolation transformer, dc wiring, ac wiring, and interconnection protection devices:	$ 477,569
TOTAL (PHOTOVOLTAIC/ROOF INTEGRATION):	$5,064,841 to $6,350,118

We can further analyze the above costs from the viewpoint of the surcharge for implementing an interconnected photovoltaic system on top of a roof which is to be built. The justification for this viewpoint is that Georgia Tech would like to have an enclosed Natatorium after the Olympics, not merely an outdoor pool and diving tank. To analyze the costs from this viewpoint, we must find out what the costs would be for a minimal functional roof over the proposed Natatorium:

* Roof Skin, including a painted insulated metal deck, purlins and connections, and a 15% contractor mark-up (these costs may be found in appendix 5, under the costs listed for Skin Scheme 1):	$ 546,166
* Gross Structure, comprised of long-span trusses[19]:	$2,178,232 to $2,262474
TOTAL (BASE ROOF ONLY):	$2,724,398 to $2,808,640

Subtracting these above base roof costs from the photovoltaic/roof integration yields a **surcharge for the photovoltaics approximately equal to $2.34 to $3.54 million.** Of these costs, we can further break down portions according to system (the costs below all include the contractor's expected 15% mark-up):

* PV Panels:	$ 888,720	(38% to 25%)
* Electrical Interface, which includes the inverter and isolation transformer, dc wiring, ac wiring, and interconnection protection devices:	$ 477,569	(20% to 13%)
* Panels' supports and weather sealing[20]	$974,154 to $2,175,189	(42% to 62%)
TOTAL (PHOTOVOLTAIC SURCHARGE):	$2,340,443 to $3,541,478	

(text continues)

---

[15] please see appendix 5 for the cost estimate worksheets

[16] the lower dollar value is Skin Scheme One (PPG 601 system on metal deck); the higher is for Skin Scheme Two (Super Sky, stick approach).

[17] This figure does not agree with PTC's number. See appendix 5 for explanation

[18] the lower dollar value is for Structural Scheme Two; the higher is for Structural Scheme One

[19] see footnote 18, above

[20] see footnote 16, above

From the above cost estimates, the least expensive roofing system is the PPG EFG 601 system. The two roofing schemes cost approximately the same. We hope to pursue other roofing and structural systems in the schematic design phase (please see Future Plans for the PV/Roof Integration Project section, following).

Acknowledgments and Authority

We'd like to thank Georgia Power Company for funding JND Sterling's efforts in this Feasibility Study, as well as their continued interest in this project. We'd also like to thank The Georgia Institute of Technology Alumni Fund for funding the Aquatic Center Design Team's efforts, as well as their continued interest.

The Aquatic Center Design Team authored most of the architectural and structural verbiage in this report, as well as estimated the architectural and structural costs associated with the roof over the Natatorium. The Aquatic Design Team is composed of the following firms (only those which participated in this effort are listed):

* Smallwood, Reynolds, Stewart, Stewart & Associates, Inc. - Joe Nuzzaco, RA & Richard Kilpatrick, RA (404) 264-0929;
* Stanley-Love-Stanley, P.C. - Tony Pickett (404) 876-3055;
* and Project Time & Cost, Inc.

We'd like to thank Advanced Photovoltaic Systems, Inc., for much assistance as well as access to their personnel and project information. We'd also like to thank all individuals and firms listed in Appendix 2.

The JND Sterling personnel associated with this feasibility study are: Dan Nall, RA & PE; Ed Ney, MS; John Hill, PE & Ph.D.; and Harris Sheinman, PE.

Future Plans for the PV/Roof Integration Project

This feasibility study is merely conceptual. In order to bring the PV/roof integration at the Natatorium to fruition, much work needs to be performed: schematic design, mock-up testing, design, procurement, construction and measurement of the integrated PV/roof array. Schematic design for the integration of the photovoltaic array into the Natatorium roof should begin immediately, in order to be integrated and concurrent with the schematic design for the swimming venue. The majority of the remaining work listed above is described in an unsolicited proposal to the Photovoltaic branch of the Department of Energy. The proposal is being prepared by JND Sterling and Advanced Photovoltaic Systems.

The entire program for design, implementation and measurement of the integrated PV/roof is shown in figure 27, following.

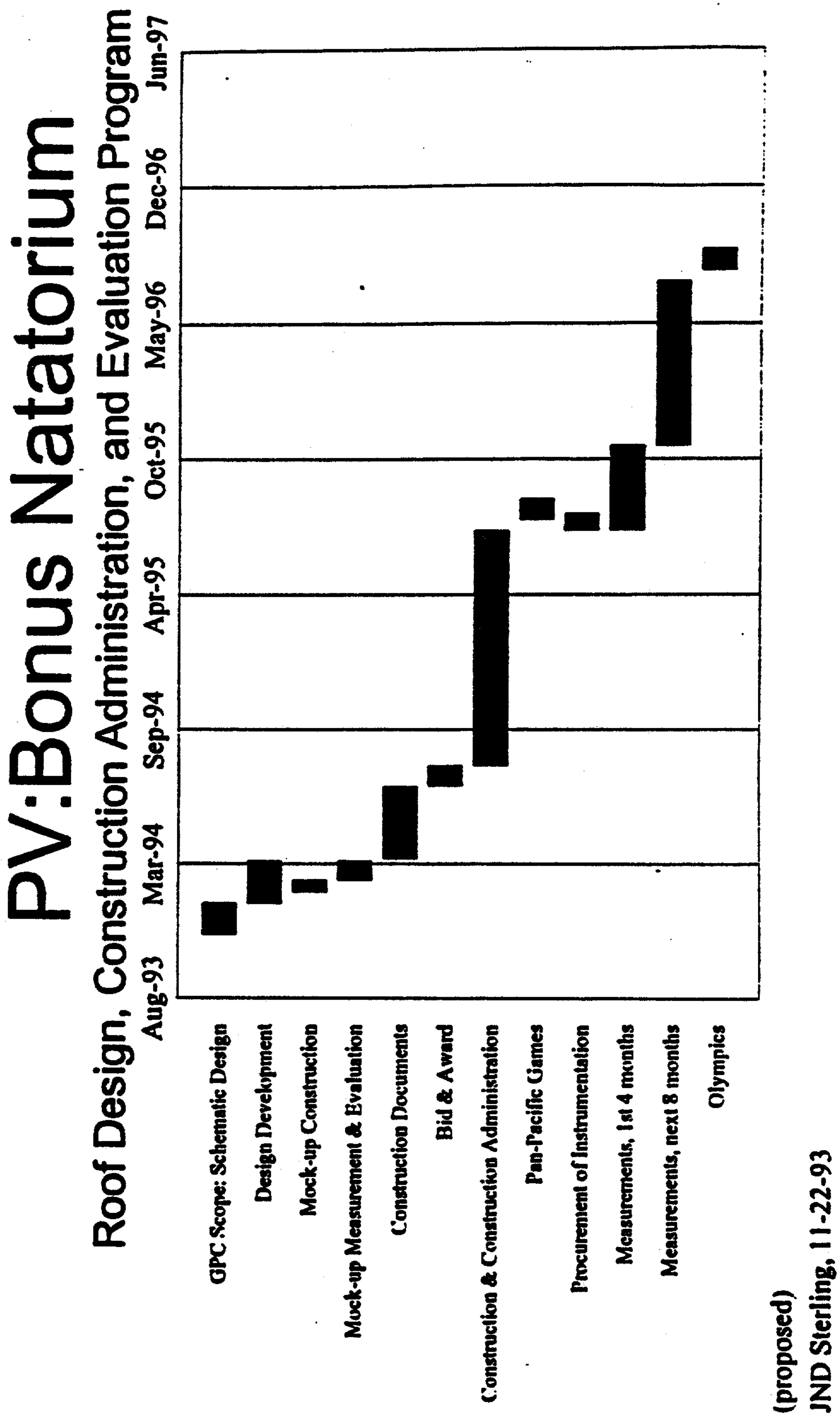
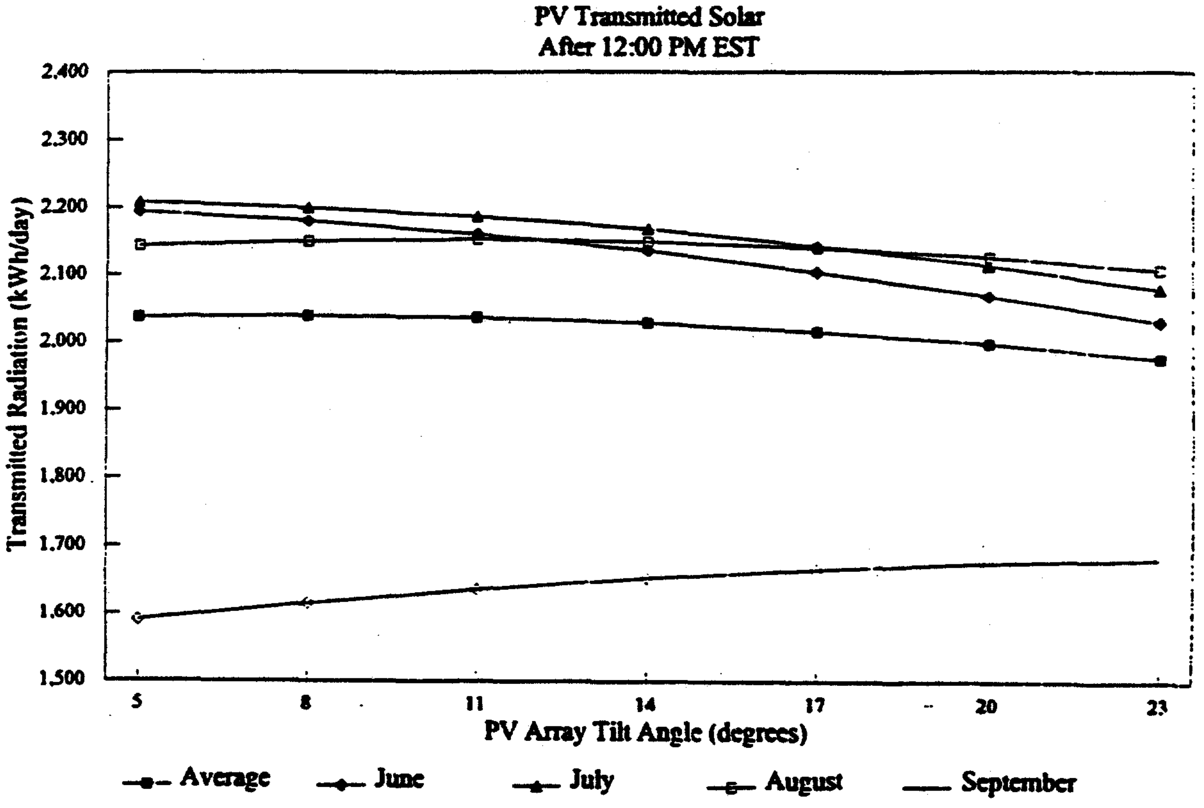


Figure 16: Bar Chart of the PV/Roof Program

APPENDIX 1: OPTIMAL TILT AND CONCEPTUAL ROOF INSOLATION CALCULATIONS

Transmitted Solar Radiation After 12:00 pm EST

	Transmitted Radiation (kWh/day)						
Tilt Angle	5	8	11	14	17	20	23
June	2,194	2,180	2,160	2,135	2,105	2,069	2,030
July	2,208	2,200	2,186	2,168	2,143	2,113	2,079
August	2,144	2,150	2,152	2,149	2,141	2,126	2,108
September	1,591	1,615	1,636	1,653	1,666	1,675	1,682
Average	2,037	2,038	2,036	2,028	2,016	1,998	1,976



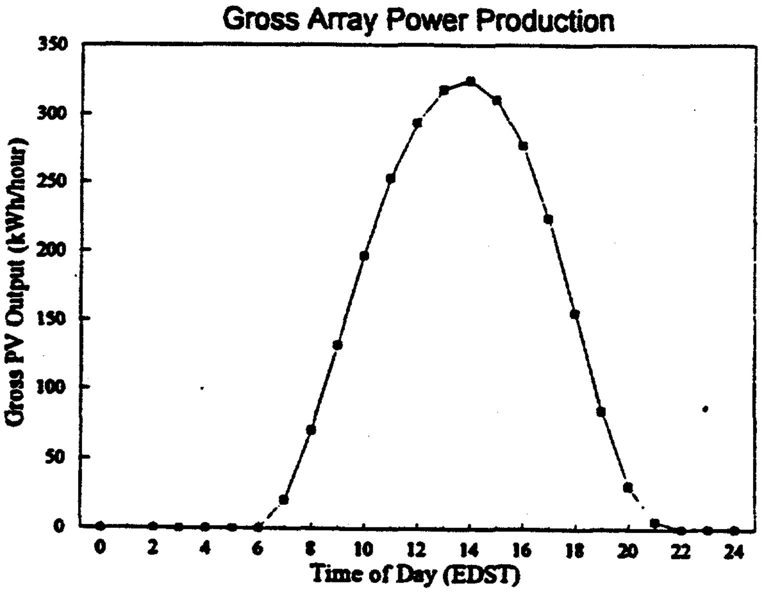
aftnoon.wk3
jmh
09/28/93

Day of Peak Power Output

6.5%	PV Cell Efficiency (3rd year)
73,000	Gross Roof Area (ft2)
64,400	Net Cell Area (ft2)
92%	Inverter Efficiency
298	Net Peak Power (kWh/hour)
14:00	Time of Peak EDST

Gross Photovoltaic Array Power Production (kWh/hour)

	Surface Tilt Angle					
Month	22	11	0	-11	-22	Design
0	0	0	0	0	0	0
1	0	0	0	0	0	
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	19	20	21	22	22	21
8	63	68	71	73	74	70
9	123	131	135	135	130	132
10	193	200	201	195	184	197
11	256	260	257	247	230	253
12	301	304	298	285	264	294
13	326	330	323	307	285	318
14	331	336	329	315	292	324
15	313	319	316	304	285	311
16	273	282	282	275	261	278
17	210	223	228	228	220	225
18	136	150	158	163	163	156
19	71	79	85	91	94	85
20	27	29	31	33	34	31
21	5	5	5	5	6	5
22	0	0	0	0	0	0
23	0	0	0	0	0	0
24	0	0	0	0	0	0
Maximum	331	336	329	315	292	324

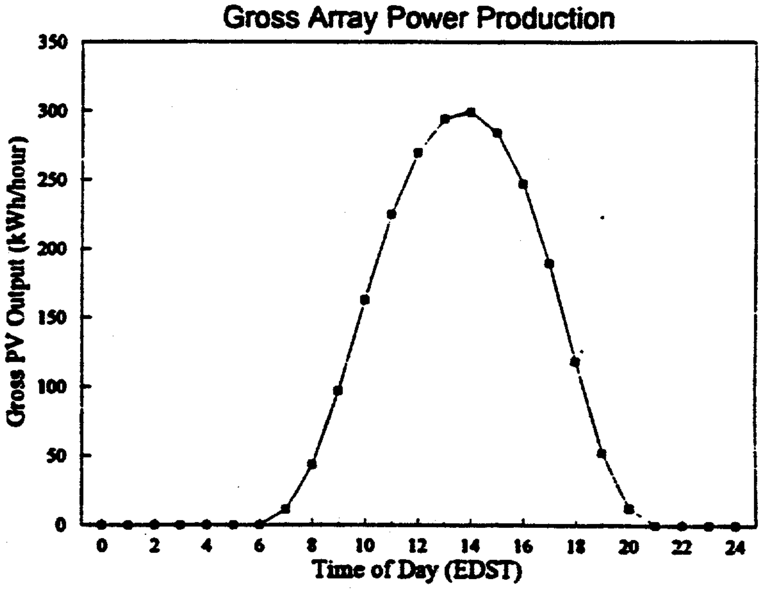


Peak August Day

6.5%	PV Cell Efficiency (3rd year)
73,000	Gross Roof Area (ft2)
64,400	Net Cell Area (ft2)
92%	Inverter Efficiency
276	Net Peak Power (kWh/hour)
14:00	Time of Peak EDST

Gross Photovoltaic Array Power Production (kWh/hour)

	Surface Tilt Angle					
Month	22	11	0	-11	-22	Design
0	0	0	0	0	0	0
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	11	11	11	11	11	11
8	43	44	44	44	43	44
9	100	101	99	95	89	98
10	175	173	167	155	139	164
11	245	240	229	212	186	225
12	294	288	274	253	223	270
13	322	314	299	276	244	294
14	326	319	304	282	251	299
15	305	301	289	270	241	284
16	260	260	252	237	214	247
17	193	197	194	185	171	190
18	114	119	121	119	113	119
19	48	51	53	54	54	52
20	11	12	12	12	13	12
21	0	0	0	0	0	0
22	0	0	0	0	0	0
23	0	0	0	0	0	0
24	0	0	0	0	0	0
Maximum	326	319	304	282	251	299



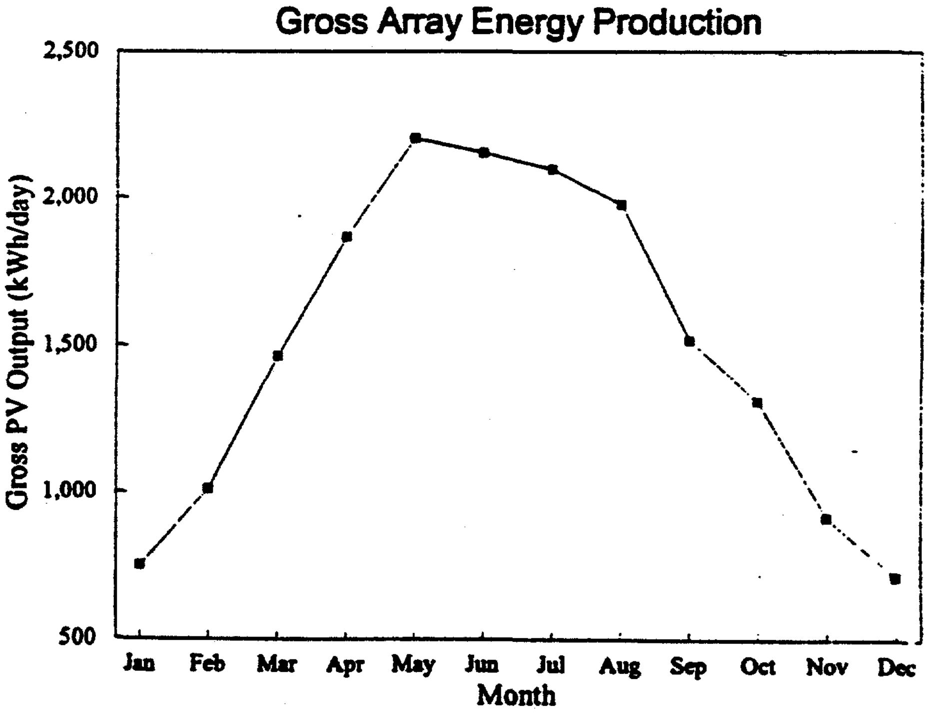
ROOFAUG1.WK3
[illegible]
13-1-93

Gross Array Energy Production

6.5%	PV Cell Efficiency (3rd year)
73,000	Gross Roof Area (ft2)
64,400	Net Cell Area (ft2)
92%	Inverter Efficiency
503,000	Annual Energy Production (kWh/year)

Monthly Gross Photovoltaic Array Energy Production (kWh/day)

	Surface Tilt Angle					
Month	22	11	0	-11	-22	Design
Jan	996	888	756	613	486	751
Feb	1,245	1,151	1,025	873	716	1,011
Mar	1,657	1,593	1,487	1,343	1,164	1,464
Apr	1,971	1,956	1,894	1,788	1,635	1,867
May	2,213	2,253	2,235	2,165	2,043	2,203
Jun	2,112	2,174	2,183	2,143	2,055	2,153
Jul	2,085	2,133	2,128	2,073	1,969	2,097
Aug	2,055	2,057	2,007	1,911	1,763	1,978
Sep	1,673	1,626	1,542	1,417	1,257	1,518
Oct	1,642	1,512	1,334	1,118	883	1,312
Nov	1,242	1,099	925	729	548	914
Dec	991	866	716	562	434	714
Average	1,657	1,609	1,519	1,395	1,246	1,498



ROOFTOT2.WK3
RMI
12-1-93

APPENDIX 2: LIST OF CONTACTS

Below is a table of persons with whom I've had useful discussions: their positions, companies, phone numbers, and areas of expertise (credentials are excluded from this list):

Contact	Position	Company	Phone	Topic
Roger Bisher; Richard Taylor	President; Electrical Engineer	Prime Power	(404) 739-2561	inverters; utility interconnection
Dick DeBlasio	Principal Engineer; Project manager: PV Modules & System Performance	National Renewable Energy Laboratory	(303) 231-1286	PV system integration; PVUSA
Bob Edgerton	Regional Sales Manager	United Solar Systems Corp.	(301) 696-1015	PV cell manufacturer
Brian Farmer	Pacific Gas & Electric	PVUSA Project Manager	(510) 866-5259	PV system integration; PVUSA
Jerry Ginn		Sandia Design Assistance Center	(505) 845-9117	inverters
Jim Gough	Project Engineer	Bechtel Construction Company	(415) 768-3262	PV system integration; PVUSA
Ted Grabowski	Executive VP	Super Sky	(414) 242-2000	architectural integration
Dick Joyce	VP	Dlubak Corporation	(412) 295-5167	architectural integration; glass manufacturer
Mark Kearns	VP	Naturalit/EPI	(214) 551-6444	architectural integration
Hans Meyer	President	Omnion Power Engineering Corp.	(414) 642-7200	inverters
Ron Matlin	Director of Power Systems Architecture and Engineering	Advanced Photovoltaic Systems, Inc.	(609) 275-0599	APS modules
Jerry Miller		Sky-Tech	(717) 752-1111	architectural integration
Hal Post	Project Manager for the Design Assistance Center	Sandia National Laboratories	(505) 844-2154	PV system integration; PVUSA
Kenneth Ragsdale		Austin Electric Department	(512) 322-6288	PV system integration
Ray Swinger	Applications Engineer	Abacus Controls, Inc.	(908) 526-6010	inverters
George Taylor	Chief Designer	Super Sky	(414) 242-2000	architectural integration
Art Wadzinsky	Product Engineer	Pilkington Glass	(416) 421-9000	architectural integration; glass manufacturer
Carl Wagus	Product Design Engineer	PPG Industries	(317) 454-2434	architectural integration
Chris Wronski	Professor, Electrical Engineering	Center for Electrical Materials and Processing, Penn State University	(814) 865-0930	PV material research scientist

APPENDIX 3: LITERATURE SEARCH: SUGGESTED BIBLIOGRAPHY / INTERVIEW INFORMATION / CODES AND STANDARDS

PHOTOVOLTAIC LITERATURE AND PAPERS

The literature listed below[21] does not include topics such as photovoltaic physics, but rather information appropriate to implementation of a photovoltaic array on a utility-interconnected scale.

Omnion Series 3200 Photovoltaic Power Conversion System Operation and Maintenance Manual, Omnion Power Engineering Corporation: describes in detail an inverter which may be used for this project.

Building-Integrated Photovoltaics, A Study Sponsored by the National Renewable Energy Laboratory, Kiss Cathcart Anders Architects: a generalized treatment of photovoltaic systems' integration into building components.

PVUSA 1992 Progress Report, Farmer and the PVUSA Project Team: provides good operational information regarding utility-scalable interconnected photovoltaic systems.

Technical Specification for the US-2 Photovoltaic Power System for PVUSA, Bechtel Construction Company: an excellent set of specifications for non-building-integrated photovoltaic arrays.

The following papers were all found in the 22nd IEEE Photovoltaic Specialists Conference:

PVUSA - Performance, Experience and Cost, Candelario, Hester, and Shipman: the capacity factors at PVUSA's flat plate Emerging Technology sites, ~10% in the winter, and ~30% in the summer, averaging to 21% over the year.

Joint EPRI/SERI Project to Evaluate Solar Radiation Measuring Systems for Utility Solar Radiation Resource Assessment, Stoffel, Riordan, and Bigger: rotating shadow band pyranometers (Ascension Technology, Lincoln Center, MA) produce accurate results, when compared to various combinations of Eppley pyranometers and pyrheliometers.

Weathering Degradation of EVA Encapsulant and the Effect of its Yellowing on Solar Cell Efficiency, Pern, Czanderina, et al: the EVA yellowing and browning results in a 9% to 50% decrease in PV array conversion efficiency.

Worldwide Systems and Applications, Ronnels: Germany has planned, by 1995, a "1000 Roofs" program fully implemented; Italy's national energy plan will have 25MW of PV's connected by 1995; Switzerland has 100kW of grid-connected PV's on road sound barriers; the U.S., in addition to its current projects (PVUSA, Va. Tech.'s solar Experiment Station, and the two Austin (TX) PV systems, the DOE introduces a Solar 2000 Program, which has a target of 100 MW of PV's connected by the year 2000.

Stability of EVA Modules, Petersen and Wolgemuth: EVA yellowing is caused by heat, not light, and the Carrisa Plant failure is due to PV fill-factor degradation, not the EVA.

---

[21] much of this literature search was performed at the Georgia Tech library, 5th floor east (TK2960 region)

Three Years of Performance and Reliability of a 15kW amorphous Silicon PV System, Atmaram, Marion, Herig: the array's conversion efficiency was 10% higher in the summer. than in the winter, possibly due to annealing effects and spectral distribution of the light.
Markets, Manufacturing and Technical Progress in Amorphous Silicon Photovoltaics in the US, Carlson: this is a very good paper describing Solarex's production processes and markets.
Application of the Standard for Safety for Flat-Plate Photovoltaic Modules and Panels, UL 1703, to Module Design, Feth: describes the UL test requirements.
Photovoltaic Equipment and The National Electric Code, Wiles: describes the Southwest Technology Development Institute's design of a GFI array disabler.

INTERVIEW INFORMATION

As a technology, photovoltaic power conversion is mature, but as a building-integrated system or a technology with proven production-capacity and quality control, the industry is still in its infancy. For the purposes of this feasibility study, JND Sterling interviewed more than two dozen figures in government, industry, utilities, and contracting. Listed below are interesting and pertinent comments:

* Ted Grabowski, **Super Sky:** He sees no reason to paint the extruded aluminum pressure plates with an epoxy or Kynar finish.

* Mark Kearns, **Naturalit/EPI:** He said that we won't be able to make a built-up insulating unit from the two lights of glass, because the silicone zipper seal does indeed leach chlorine gas (just like water vapor leaching into polyvinyl buteryl (PVB) lamination material). The chlorine gas de-activates the desiccant material that the manufacturer puts in between the two panes to eat up the water vapor which leaches through the silicone. Without the desiccant material between the lights, one finds that water evaporates and condenses between the two panes, thus removing most of the insulating qualities of the glass. One may still have normal double-pane glass, but such glass will not prevent condensation on the surfaces.

* Brian Farmer, **PG&E**: The degradation of the APS modules was 11% over the first year (these figures were measured after three months of unmeasured exposure), indicative of Staebler-Wronski degradation. The APS' array 12-pulse SCR inverter has had problems when the utility had line disturbances. His one concern about the amorphous silicone technologies is that they are not very efficient in their power conversion; one would need a lot more surface area per unit power production, a feature well worth considering in our project. In our design, we must address, on the dc side, power precautions for line integrity because of high voltages. The OSHA cutoff for bare-handed service is 50V (8-10 of the PV panels in series goes to 400+ volts). One should over-rate the inverter, to be safe from solar enhancements' transients. Inverters seem to be the Achilles heal of the PV systems.

* Chris Wronski, **PSU:** The Staebler/Wronski effect is still not explained by the scientists; he believes that the degradation could be due to white light. The degradation stabilizes (saturates?) with lighted time.

* Ray Swinger, **Abacus:** His inverter uses the line utility to synchronize the inverter's internal clock. They use bipolar transistors instead of SCR's. This is a full-bridge (commutated) programmed-waveform (PWM) inverter. SCR's have a lot of EM/RFI noise. With a PWM inverter, no zero crossing on the voltage is needed (it is with SCRs, to shut off the current

flow). His prices are: 100kW = $65,000.00. A 300 kW system is 3 of these 100 kW inverters paralleled. One of the selling points of his inverter is that it isolates the dc side from the utility with a transformer: a failure in the bridge does not cause direct dc to go into the utility line. The inverter produces power at very near unity pf. The total harmonic distortion is 2% or less. The old Abacus design (the one which was twitchy in the Georgia Power Future One House program) was PWM, but could be run stand-alone or utility-line driven. The new Abacus unit has more state-of-the-art circuiting. Abacus is currently providing 16 inverters (500 VA ea.) to Georgia Power for Plant Hatch, supporting its Black-Start System. The PV array will act as a giant antenna with the EM/RFI noise back to the dc side of the inverter. The Abacus inverter has EM/RFI filters internally. The Abacus inverter efficiency is 92%, but drops off at 40% of power load.

* Jerry Ginn, **Sandia Design Assistance Center**: Abacus and Omnion make similar products, which are intended to function with utilities. They both use IGBT's, which are much more robust than SCR's. The inverters work on a voltage window. As soon as the sun comes up, the array's voltage develops quickly. Ripple voltage on the dc side is not a concern. The EM/RFI problem has not yet been measured. The 93% to 95% efficiency claims are optimistic; 90%+/- is more reasonable (Omnion is a little more efficient (1-2%) than the Abacus, because it does not have a transformer, but the transformer does give electrical isolation from dc injection into the utility line). The Omnion machine is designed with a bi-polar array (+,N,-). The wiring gauge, at the higher line-line voltage, may be smaller than that in a unipolar array, as less amperage is drawn (per unit power production), and the switches may also be smaller. The downside with the higher line-line voltage is that we will need to specify devices and cable insulation for the higher voltage, perhaps above the 600V cusp.

* Hans Meyer, **Omnion**: Line-to-line voltages greater than 600V afford us greater line efficiencies (less line losses), as well as greater inverter efficiencies, but we do have to protect/specify devices to about 1200V (5KV?) protection. We can save on the rating/protection if we go with the lower line-to-line voltage, but we pay with a larger inverter as well as a greater line and inverter inefficiency. The inverters cost, in our size range and at greater-than 600V line/line, about 70 to 80 cents per watt (the higher figure includes the transformer and all of the dc-side fused switches and blocking diodes as well as the ac-side interconnection accessories); a 10 to 15 cent/watt premium would be charged if we go to the less-than 600V line/line transformer.

* Kenneth Ragsdale, **Austin (Texas) Electric Department:** His recommendation is to place the PV surface above the weather seal (because if modules serving as the weather seal break, changing them is so much more difficult, and the seals' integrities are always a question). The inverter is a problem component: the inverters' crashing causes most of the systems' down-time. He has various other suggestions: design easy access to the back of the panels; and keep the modules out of the roofing system. He has two further comments: the EVA problem is not solved, nor has it been proven to be a big problem; and the large line/line voltages pose no problem (Austin's equipment is served by utility personnel), but the wiring for greater than 600V requires a better-rated insulation jacket.

* Hal Post, **Sandia National Laboratories**: He has little to say about the APS module one way or another, but he thinks the technology's efficiency is poor. The light induced degradation (Staebler/Wronski effect) hasn't been solved, nor does he think that it ever will be. We should be at about 4% efficiency after all component inefficiencies have been considered. Conventional wisdom in the industry is that if the system had less than 4% efficiency, the PV

manufacturers could give their cells to you for free, and you still couldn't build it. as all of the ancillary equipment and structure would render the installation's payback prohibitively long. USSC is another thin-film PV manufacturer; they make a flexible ribbon module which may be more appropriate to an opaque roof, but it too has a low conversion efficiency. GSA has three listed crystalline [non-amorphous] module manufacturers/vendors, and their prices all cluster around $4.50-$5.00/watt. His last piece of information is that the main problem will be down-time frequency, and that's mostly resident in the power processing system (inverters). Apparently, the market just isn't big enough to support the really large power equipment vendors. When asked why the UPS market hasn't seen such down-time problems, he contrasted the UPS market's inversion efficiencies of 75% against the PV market's needs for 90%+ efficiencies as a driver in the short mean-time-between-failures.

SALIENT BUILDING CODES AND STANDARDS

This below list is attached from internal JND Sterling working notes, listing all (that we could find) of the standards and codes which address aspects of the PV/roof integration for the Natatorium. It is not written in a formal fashion, and many of the standards and codes may, in fact, not be applicable to the final design.

REGARDING UTILITY INTERCONNECTION:

Georgia Power Company's Bulletin 51: Guide for Interconnection Requirements and Parallel Operation of Customer-Owned Generation. Of course this guide applies, even though we're paralleling the GIT power grid. We must worry about power quality and islanding.

NFPA 70 paragraphs 690 and 750: Solar Photovoltaic Systems and Interconnected Electric Power Production Sources. These paragraphs in the National Electric Code deal with protection to personnel and equipment of interconnected PV systems.

IEEE Publication 88 THO224-6-PWR: Intertie Protection of Consumer-Owned Sources of Generation, 3 MVA or Less. I've no text on this, but GPC's Bulletin 51 references it. When design stage arrives, we should look at it.

IEEE 80: Guide for Safety in Substation Grounding. This is a very basic standard, much like NFPA 70. It does write about soil conductances and grounding design to a certain degree of detail. It speaks only to grounding of ac substations; no writing is provided for dc stations. For that, see the 1958 Report of the Conversion Substation Committee.

IEEE 430: Guide for the Installation of Electrical Equipment to Minimize Electrical Noise Inputs to Controllers from External Sources. This standard speaks to the protection of industrial controllers, and the like, from system noise. It may have marginal application in our project.

IEEE 469: Recommended Practice for Voice-Frequency Electrical-Noise Tests of Distributed Transformers. This standard quantifies telephone influence factors of various voltage and current harmonics, as the harmonics to interfere with the phone transmission.

IEEE 519: Recommended Practices and Requirements for Harmonic Control in Electric Power Systems. This standard speaks directly to the harmonics issue: why they're dysfunctional for the system and its users, what limits to allow, how to correct for them.

IEEE 929: Recommended Practice for Utility Interface of Residential and Intermediate PV Systems. This standard is, of necessity, quite vague, and merely defines all of the aspects at which a system integrator should look. We address all of these issues in this feasibility study.

IEEE 1001: Guide for interfacing Dispersed Storage and Generation Facilities with Electric Utility Systems. I've no text on this, but GPC's Bulletin 51 references it. When design stage arrives, we should look at it.

EPRI AP/EM-3124-1983: Interconnecting DC Energy Systems. Response to Technical Issues. I have not reviewed this standard, but IEEE 929 references it. When design stage arrives, it should be studied.

ANSI C2: National Electrical Safety Code. This code deals with protection to personnel and equipment of electrical systems.

ANSI/IEEE C37: Circuit Breakers, Switch gear, Relays, Substations and Fuses. This standard is very basic, and should merely be listed.

ANSI/IEEE C57: Distribution, Power and Regulating Transformers. This standard too is very basic, and should also merely be listed.

ANSI/IEEE C63.4: Methods of Measurement of Radio-Noise Emissions from Low-Voltage Electrical and Electronic Equipment in the Range of 9 KHz to 40 GHz. This standard is a broad, boilerplate type of standard, and applies to *everything*.

REGARDING PHOTOVOLTAIC SYSTEMS:

NFPA 70 paragraphs 690 and 750: Solar Photovoltaic Systems and **Interconnected Electric Power Production Sources.** These paragraphs in the National Electric Code deal with protection to personnel and equipment of interconnected PV systems.

SERI/TR-213-3624: Interim Qualification Tests and Procedures for Terrestrial Photovoltaic Thin-Film Flat-Plate Modules. This document prescribes acceptance tests for thin-film PV modules, much like those used in the PVUSA installation. The tests attempt to check the weatherability and the electrical sturdiness and seal of the modules.

IEEE 928: Recommended Criteria for Terrestrial PV Power Systems. This standard is, of necessity, quite vague, and merely defines all of the aspects at which a system integrator should look. We address all of these issues in this feasibility study.

IEEE 929: Recommended Practice for Utility Interface of Residential and Intermediate PV Systems. This standard is, of necessity, quite vague, and merely defines all of the aspects at which a system integrator should look. We address all of these issues in this feasibility study.

ANSI/UL 1703: Standard for Safety for Flat-Plate Photovoltaic Modules and Panels. As the PV array is to be integral with the building construction, it must comply with building codes, which recognize NFPA 70 as governing electrical construction. NFPA 70 says that PV equipment must be listed, and this standard is UL's answer to that requirement.

ASTM E 927: Standard Specification for Solar Simulation for Terrestrial Photovoltaic Testing. This standard classifies solar collectors according to their spectral match to standard light spectra, their stability with time, and their uniformity.

ASTM E 948: Standard Test Methods for Electrical Performance of Non-Concentrator Terrestrial Photovoltaic Cells Using Reference Cells. This standard's methods are used to determine various operating parameters of the PV cells: Voc, Isc, efficiency, maximum power, and the like. This standard could also bear the number E 1036.

ASTM E 1036: Standard Methods of Testing Electrical Performance of Nonconcentrator Terrestrial Photovoltaic Modules and Arrays Using Reference Cells. This standard's methods are used to determine various operating parameters of the PV arrays: Voc, Isc, efficiency, maximum power, and the like.

ASTM E 1038: Standard Practice for Determining Resistance of Photovoltaic Modules to Hail by Impact with Propelled Ice Balls. We must definitely address and use this standard. This was taken from NREL interim qualification test.

ASTM Draft #192: Standard Test Method for Natural and Artificial Solar Radiation Weathering Tests of Non concentrating Photovoltaic Modules. This was a draft. as of the 1991 IEEE Photovoltaic Conference. This draft standard contains 3 separate solar/UV weathering tests, all of which simulate 3 years exposure.

ASTM Draft #196: Standard Test Methods for Insulation Integrity and Ground Path Continuity of Photovoltaic Modules. This was a draft, as of the 1991 IEEE Photovoltaic Conference. This draft standard provides the methods to hi-pot test the insulation of the PV modules.

ASTM Draft #199: Standard Test Method for Wet Insulation Resistance of Photovoltaic Modules. This was a draft, as of the 1991 IEEE Photovoltaic Conference. This draft standard tests the insulation of the modules when they are wet, which affords a sensitive test of the modules' insulation.

REGARDING MECHANICAL ASPECTS OF PV ROOF MOUNTING:

SBC, paragraphs 707 and 2605: Sloped Glazing and Skylights. These paragraphs in the Standard Building Code prescribed safe constructions for skylights.

ASTM B 308: Standard Specification for Aluminum-Alloy 6061-T6 Standard Structural Shapes. This standard may address issues involved with the pressure plates and skylight structure. It has a whole bunch of related ASTM Standards referenced to it, which I didn't list here. This standard speaks to the question of how one may order the extruded metal.

ASTM B 429: Standard Specification for Aluminum-Alloy Extruded Structural Pipe and Tube. This standard may address issues involved with the pressure plates and skylight structure. It has many related ASTM Standards referenced to it, which I didn't list here. This standard speaks to the question of how one may order the extruded metal.

ASTM C 271: Standard Test Method for Density of Core Materials for Structural Sandwich Constructions. This standard may address issues involved with the fabrication of opaque curtain walls. We'd want to reference this standard when the mock-up testing is required.

ASTM C 272: Standard Test Method for Water Absorption of Core Materials for Structural Sandwich Constructions. This standard may address issues involved with the fabrication of opaque curtain walls. We'd want to reference this standard when the mock-up testing is required.

ASTM C 273: Standard Test Method for Shear Properties in Flatwise Plane of Flat Sandwich Constructions of Sandwich Cores. This standard may address issues involved with the fabrication of opaque curtain walls. We'd want to reference this standard when the mock-up testing is required.

ASTM C 393: Standard Test Method for Flexural Properties of Flat Sandwich Constructions. This standard may address issues involved with the fabrication of opaque curtain walls. We'd want to reference this standard when the mock-up testing is required.

ASTM C 509: Standard Specifications for Cellular Elastomeric Preformed Gasket and Sealing Material. This standard may address issues involved with the fabrication of the skylight panes into insulating units or into a skylight itself. We ought to specify that any sealing materials bear notification of compliance with this standard.

ASTM C 542: Standard Specifications for Lock-Strip Gaskets. This standard may address issues involved with the fabrication of the skylight panes into insulating units or into a skylight itself. It specifically speaks to the gasket's flame propagation and lip "clenching" characteristics.

ASTM C 669: Standard Specifications for Glazing Compounds for Black Bedding and Face Glazing of Metal Sash. This standard may address issues involved with the fabrication of the skylight panes into insulating units or into a skylight itself. This standard talks to a rubbery bed on which the glazing sets. Maybe it's appropriate, maybe not.

ASTM C 716: Standard Specifications for Installing Lock-Strip Gaskets and Infill Glazing Materials. This standard may address issues involved with the fabrication of the skylight panes into insulating units or into a skylight itself. This is indeed an important standard when speaking to the fabrication and erection of the skylight!

ASTM C 719: Standard Test Methods for Adhesion and Cohesion of Elastomeric Joint Sealants Under Cyclic Movement. This is a good method to reference when speaking to the fabrication of the insulating units which will be dropped into the skylight's extruded aluminum framing. Only the tests attached to float glass are, of course, appropriate.

ASTM C 864: Standard Specifications for Dense Elastomeric Compression Seal Gaskets, Setting Blocks, and Spacers. This standard might be appropriate to the fabrication and detailing of pressure plates and the like, although I do have my doubts.

ASTM C 964: Guide for Lock-Strip Gasket Glazing. I have no text on this standard.

ASTM D 15: Standard Methods for Compound and Sample Preparation for Physical Testing of Rubber Products. This standard may address issues involved with the fabrication of the skylight panes into insulating units or into a skylight itself. There is no text to read on this one.

ASTM D 395: Standard Test Methods for Rubber Property-Compression Set. This standard should only be listed, as it appears to be too basic to be extremely helpful.

ASTM D 412: Standard Test Methods for Rubber Properties in Tension. This standard should only be listed, as it appears to be too basic to be extremely helpful.

ASTM D 573: Standard Test method for Rubber-Deterioration in an Air Oven. This standard is somewhat appropriate to the project, as the PV panels will indeed elevate the temperature of the gaskets. If the gaskets are rubber, then we must address it. It says it may be used with other than vulcanized rubbers as well as vulcanized.

ASTM D 624: Standard Test Method for Rubber Property-Tear Resistance. This standard only applies to vulcanized rubber; is it appropriate?

ASTM D 638: Standard Test Method for Tensile Properties of Plastics. This standard would be used if the project employed materials such as Kalwall, or the like. It is a very basic test, however.

ASTM D 746: Standard Test Method for Brittleness Temperature of Plastics and Elastomers by Impact. This standard develops the temperature at which 50% of the sample plastics are brittle, and has use in finding the appropriateness of certain materials for the gasketing.

ASTM D 865: Standard Test Method for Rubber-Deterioration by Heating in Air (test Tube Enclosure). This standard may address issues involved with the fabrication of the skylight panes into insulating units or into a skylight itself. There is no text to read on this one.

ASTM D 925: Standard Test Methods for Rubber Property-Staining of Surfaces (Contact, Migration and Diffusion). There is no text to read on this one.

ASTM D 1003: Standard Test Methods for Haze and Luminous Transmittance of Transparent Plastics. Very useful standard, if we are to use the Kalwall materials in the weatherproofing.

ASTM D 1044: Standard Test Method for Resistance of Transparent Plastics to Surface Abrasion. Very useful standard, if we are to use the Kalwall materials in the weatherproofing.

ASTM D 1149: Standard Test Method for Rubber Deterioration-Surface Ozone Cracking in a Chamber. This standard is somewhat appropriate to the project, if the gaskets are rubber. The standard says it may be used with vulcanized rubber.

ASTM D 1330: Standard Specifications for Gaskets, Rubber Sheet. This standard is somewhat appropriate to the project, if the gaskets are rubber. The standard says it may be used with ordinary gaskets cut from sheet rubber.

ASTM D 1654: Standard Test Methods for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments. This standard may address issues involved with the pressure plates and skylight structure.

ASTM D 1735: Standard Practice for Testing Water Resistance of Coatings Using Water Fog Apparatus.

ASTM D 1763: Standard Specifications for Epoxy Resins. This standard may address issues involved with the epoxy coatings of the skylight structure.

ASTM D 2247: Standard Practices for Testing Water Resistances of Coatings in 100% Relative Humidity. This standard is very useful when testing a mock-up of a skylight assembly, and the coatings covering the extruded metal.

ASTM D 2249: Standard Test Method for Predicting the Effect of Weathering on Face Glazing and Bedding Compounds on Metal Sash. I've no text for this standard.

ASTM D 2376: Standard Test Method for Slump of Face Glazing and Bedding Compounds on Metal Sash. I've no text for this standard.

ASTM D 2451: Standard Test Method for Degree of Set for Glazing Compounds on Metal Sash. I've no text for this standard.

ASTM D 3039: Standard Test Method for Tensile Properties of Fiber-Resin Composites. I've no text for this standard.

ASTM D 4585: Standard Practice for Testing Water Resistance of Coatings Using Controlled Condensation. I've no text for this standard.

ASTM E 331: Standard Test Methods for Water Penetration of Exterior Windows, Curtain Walls, and Doors by Uniform Static Air Pressure Differential. This standard would be a good one to reference when talking about testing the mock-up.

ASTM E 424: Standard Test Methods for Solar Energy, Transmittance and Reflectance (Terrestrial) of Sheet Materials. This standard addresses very basic issues regarding glass transmittance, and should only be glancingly acknowledged.

ASTM E 547: Standard Test Methods for Water Penetration of Exterior Windows, Curtain Walls, and Doors by Cyclic Static Air Pressure Differential. This standard would be a good one to reference when talking about testing the mock-up.

ASTM E 773: Standard Test Methods for Seal Durability of Sealed Insulating Glass Units. This standard seems to be appropriate to the project if we go with the skylight option.

ASTM E 774: Standard Specification for Sealed Insulating Glass Units. This standard too is appropriate if we go with the skylight option.

ASTM E 838: Standard Practices for Performing Accelerated Outdoor Weathering Using Concentrated Natural Sunlight. This standard describes testing for weathering, under sunlight, of plastics, like EVA. This might be appropriate to the project for the testing of EVA yellowing.

ASTM E 903: Standard Test Methods for Solar Absorptance, Reflectance, and Transmittance of Materials Using Integrated Spheres. This standard describes some of the basic tests a glass can be subjected to; we may merely want to list it, as it is probably too basic to be of use.

ASTM F 36: Standard Test Methods for Compressibility and Recovery of Gasket Materials. This standard may not be applicable, as it does not address creep or compression set, but rather only short-term compressions, and their recovery.

ASTM F 37: Standard Test Methods for Sealability of Gasket Materials. I don't have any text on this standard, but it seems to be the most appropriate of this block.

ASTM F 104: Standard Classification for System for Nonmetallic Gasket Materials. A useful standard for the specifications in the project.

ASTM F 146: Standard Test Methods for Fluid Resistance of Gasket Materials. I really don't think that this standard could apply.

ASTM F 147: Standard Test Method for Flexibility of Non-Metallic Gasket Materials. I've no text for this standard.

ASTM F 152: Standard Test Methods for Tension Testing of Nonmetallic Gasket Materials. I've no text for this standard.

ASTM F 607: Standard Test Method for Adhesion of Gasket Materials to Metal Surfaces. I've no text for this standard.

ASTM G 1: Standard Practices for Preparing, Cleaning, and Evaluating Corrosion Test Specimens. This standard could be useful when looking at the swimming pool air corroding the skylight and/or cladding and/or macro structure of the roof.

ASTM G 46: Standard Practices for Examination and Evaluation of Pitting Corrosion. This standard could be useful when looking at the swimming pool air corroding the skylight and/or cladding and/or macro structure of the roof.

ASTM G 60: Standard Test Method for Conducting Cyclic Humidity Tests. This standard may be used with the corrosion testing or with the PV material durability testing.

ASTM G 90: Standard Practices for Performing Accelerated Outdoor Weathering of Nonmetallic Materials Using Concentrated Natural Sunlight. This standard's test apparatus may be used to look at the EVA yellowing as well as other UV durability issues.

APPENDIX 4: MECHANICAL AND ELECTRICAL BLOCK LOADS' CALCULATIONS

ENCLOSED NATATORIUM HVAC LOADS' WORKSHEET

Item	**Areas/ Counts**	**U/SC**	**CLTD/ SHGF**	**Cooling Loads**				**Heating Loads**
				Sensible	**Latent**	**Total**	**%**	
Roof(1)	60450	0.0720	85.37	371564		371564	7.3	304668
N Wall & Glass, Cond.(1)	21080	0.1300	28.37	77745		77745	1.5	191828
E Wall & Glass, Cond.(1)	9750	0.1300	35.37	44831		44831	0.9	88725
S Wall & Glass, Cond.(1)	23250	0.1300	46.37	140153		140153	2.7	211575
W Wall & Glass, Cond.(1)	16575	0.1300	45.37	97761		97761	1.9	150832
N Glass, Solar(2)	5270	0.57	38	114148		114148	2.2	
Miscellaneous Equipment	60450	0.25	3.413	51579		51579	1.0	
Lights(3)	60450	1.5	3.413	309474		309474	6.1	
People(4)	16	710	105	11360	1680	13040	0.3	
	3000	245	105	735000	315000	1050000	20.6	
Pool Latent(5)	21586	0.04070	1049.16		921808	921808	18.1	
Room Subtotals				1953616	1238488	3192104	62.6	947628
Room Sensible Heat Ratio	0.612							
Supply Airflow	157325cfm; a-c/h =		2.00					
			80°F/55%= RMT					
Coil Airflow(9)	82624cfm		56.7/55.4= LAT					
Bypass Airflow(9)	74701cfm		66.5= SA MAT					
			68.5= SAT					
Reheat (from S/A MAT)	157325	1.08	-0.025	-4248		-4248	-0.1	
Fan Heat-R/A(6)	157325	1.08	0.025	4248		4248	0.1	
Fan Heat-S/A(6)	157325	1.08	1.025	174159		174159	3.4	
Outside Air(7)	43425	1.08	12	562788		562788	11.0	3282930
	43425	0.6914	22		660556	660556	13.0	
Duct Heat, S/A(8)	157325	1.08	1	169911		169911	3.3	
Duct Heat, R/A(8)	157325	1.08	2	339822		339822	6.7	
Totals				3200296	1899044	5099340	100.0	4230559
Apply Factors of Safety				3360310 (1.05 FS)				5076670 (1.2 FS)
	cshr =	0.639						
Grand Total Heats (Cooling and Heating)						5259355btuh		5076670btuh
Tons/MBH						438tons		5077mbh
Checksums						138sf/ ton		84btuh/sf

Natatorium HVAC Loads' Worksheet Notes:

(1)The walls and roof U-values are in accordance with ASHRAE Standard 90.1-1989, table 8A-8
(2)The glass area is approximately 20% of facade area
(3)The lighting load is found in accordance with ASHRAE/IES Standard 90.1-1989, UPD Method
(4)The people load is equal to 2 x swimming lanes x strenuous load + 75% occ x 4000 seats x seated load
(5)The pool's latent load is calculated in accordance with the 1991 ASHRAE Applications Handbook, P.4.7
(6)Fan heat is calculated as follows: supply airflow (found psychrometrically and from room loads) is multiplied by the 1.08 conversion and an engineered estimate of the fan temperature gains, 0.45 degrees F per inch of total static pressure engaged by fan
(7)Outside Airflow is found by applying ASHRAE Standard 62-1989, Table 2.1: 0.5 cfm/sf and 1/2 x 15 cfm/pers
(8)Duct heat is calculated as follows: supply airflow (found psychrometrically and from room loads) is multiplied by the 1.08 conversion and an engineered estimate of the duct pickup temperature gains, 1 degree F on the supply ducting, and 2 degrees F on the return ducting
(9)The coil airflow and bypass airflow are both found using adiabatic mixing

ENCLOSED NATATORIUM ELECTRICAL LOADS' WORKSHEET

Item	**Load Dens. Watts/sf**	**Area SF**	**Connected Load, Volt-Amps**
Lighting	2	60450	120900
Add 25% for continuous loading			30225
Miscellaneous Power	0.5	60450	30225
HVAC: chiller, 265 tons, 0.6kW/ton, 125%, 0.80pf (tonnage based on 60% of block load)			248438
HVAC: chiller, 265 tons, 0.6kW/ton, 0.80 pf (tonnage based on 60% of block load)			198750
HVAC: cooling tower, 2x25hp fans			56534
HVAC: CW Pumps, 2 x 30hp			66510
HVAC: CHW Pumps, 2 x 30hp			66510
HVAC: AHU's, 8pc's, 25 hp ea.			226136
HVAC: Fans, 8 pc's, 25hp ea.			226136
HVAC: Misc. (20% of all other HVAC)			217803
PLMBG: Pool Pumps (20hp & 40hp)			65679
Subtotal			**1553845VA**
Auxiliaries			77692
Total Present Load			**1632kVA**
Allowance for 20% growth			326
Future Total			**1958kVA**

Natatorium Electrical Block Loads' Conclusions:

- Building Utilization Voltage is 480Y/277.
- Transformer is 2000 kVA, with a 2500 A fused Service Entrance switch.
- No demand factors have been taken, in accordance with NEC, as the transformer must be sized per NEC (it's GIT's transformer, not GPC's).

APPENDIX 5: COST ESTIMATE WORKSHEETS

ELECTRICAL COST ESTIMATE

(this estimate by JND Sterling)

Item	Qty	Unit Cost	Extension
DC			
Wiring:			
#4 5KV Cu CLP shielded cable, 2,660' per panel	18620	$2.80	$52.136
Cast (weatherproof) junction boxes, 138 per panel	966	$53.50	$51.681
3/4" rigid steel conduit, 2,660' per panel	18620	$5.85	$108.927
SUBTOTAL			$212.744
Inverters, including isolation transformer, (7) panels fused switches w/blocking diodes, max-power-trackers, dc disconnects, and all necessary protection and alarm devices: 2 x 150 kVA inverters	300000	$0.80	$240.000
AC Wiring and Protection:			
Two sets of (4) #350 MCM & (1)#1G-3"C AC feeder cabling	200	87.5	$17,500
600A/480V molded case (NEMA 1) circuit breaker (transformer disconnect)	1	2450	$2,450
600A/480V heavy duty fused disconnect switch	1	2550	$2.550
600A/480V solid state circuit breaker, for mounting in the Natatorium's main switchboard	1	2325	$2,325
SUBTOTAL			$24,825
TOTAL ELECTRICAL COSTS (INCLUDES CONTRACTORS MARK-UP):			**$477.569**

Following are copies of the ACDT estimates:

Note that the report does not use Project Time & Cost's estimate for the PPG 601 cladding system. We've further interviewed the [North Carolina] vendor - Steve Cassell, CDC Enterprises, (910) 288-2464 - of the PPG 601 system, and found that his numbers had a safety factor of approximately 10%, as all the work has merely been conceptual. We also cross-checked the local vendor's costs against PPG Industries' corporate personnel - Carl Wagus, listed in appendix 2 -, and they feel that we may, for budgeting purposes, easily deduct 20% from the local vendor's price, citing that the vendor was quite conservative in his estimate.

Georgia Tech Aquatic Center				
Roof Scheme Comparisons				
SKIN SCHEME 1 - PPG ON METAL DECK				
Paint Underside of Deck	73025	SF	0.40	29,210
20 Gauge B Deck	73025	SF	1.20	87,630
1-1/2" Rigid Insulation	73025	SF	1.25	91,281
Roof Membrane	73025	SF	2.25	164,306
PPG 601	73025	SF	14.20	1,036,955
PV Panel	5152	EA	150.00	772,800
Purlins - 6' OC	55	Ton	1,500	82,500
15% for Connections (Purlins)	8	Ton	2,500	20,000
			Subtotal	2,284,682
Prime Contractor Markup (15%)				343,000
			TOTAL	2,627,682
SKIN SCHEME 2 - SUPER SKY (Stick Approach)				
Super Sky System	73025	SF	27.00	1,971,675
1-1/2" Ceiling Insulation Panel and Suspension System	73025	SF	4.00	292,100
(Acoustical Face)				
PV Panel	5152	EA	150.00	772,800
Purlins on 10'-7" Centers	55	Ton	1,500	82,500
15% for Connections (Purlins)	8	Ton	2,500	20,000
			Subtotal	3,139,075
Prime Contractor Markup (15%)				471,000
			TOTAL	3,610,075
SKIN SCHEME 3 - SUPER SKY (Panel Approach)				
Super Sky System	73025	SF	23.00	1,679,575
Panel Material, Assembly, and Shipping	73025	SF	7.00	511,175
2" Panel with Painted Aluminum Face				
PV Panel	5152	EA	150.00	772,800
Purlins on 10'-7" Centers	55	Ton	1,500	82,500
15% for Connections (Purlins)	8	Ton	2,500	20,000
			Subtotal	3,066,050
Prime Contractor Markup (15%)				460,000
			TOTAL	3,526,050

Georgia Tech Aquatic Center				
Roof Scheme Comparisons				
STRUCTURAL SCHEME 1				
Steel				
Horizontal Elements	Quantity	UM	Unit Cost	Total Cost
Bow Truss	95	Ton	1,700	161,500
Center Truss	183	Ton	1,700	311,100
Spandrel Truss	270	Ton	1,700	459,000
Vertical Elements				
Box Truss	60	Ton	1,700	102,000
Precast Concrete Enclosure	24000	SF	12	288,000
15% for Connections	91	Ton	2,500	227,500
Other Items				
78" square Concrete Column - 4 ea - 70' Tall	438	CY	230	100,774
Large Column Special Foundation	2800	VLF	21	58,800
20-100 Ton Pile - 2 Places - 70' Long - 18" Dia				
Small Column Special Foundation - 10-100 Ton Pile	2800	VLF	21	58,800
10-100 Ton Pile - 4 Places - 70' Long - 18" Dia				
Architectural features	1	LS	200,000	200,000
			Subtotal	1,967,474
Prime Contractor Markup (15%)				295,000
			TOTAL	2,262,474

Georgia Tech Aquatic Center				
Roof Scheme Comparisons				
STRUCTURAL SCHEME 2				
Steel				
Horizontal Elements	Quantity	UM	Unit Cost	
Bow Truss	108	Ton	1,700	183,600
Off Center Truss	286	Ton	1,700	486,200
Vertical Elements				
Box Truss	80	Ton	1,700	136,000
Precast Concrete Enclosure	24000	SF	12	288,000
15% for Connections	71	Ton	2,500	177,500
Other Items				
48" Square Concrete Column - 15 Ea - 70' Tall	622	CY	460	286,222
Large Column Special Foundation	3360	VLF	21	70,560
24-100 Ton Pile - 2 Places - 70' Long - 18" Dia				
Small Column Special Foundation	3150	VLF	21	66,150
3-100 Ton Pile - 15 Places - 70' Long - 18" Dia				
Architectural Features	1	LS	200,000	200,000
			Subtotal	1,894,232
Prime Contractor Markup (15%)				284,000
			TOTAL	2,178,232

Removed for
Separate processing