SOLAR 2001 CONFERENCE: SOLAR FACTORY OF THE FUTURE – SPRINGER CARRIER CANOAS, BRAZIL.

Michael H. Nicklas
Duke Solar
Innovative Design, Inc.
Jon Zubizarreta
Innovative Design, Inc.
850 W. Morgan St.
nicklas@innovativedesign.net
jon@innovativedesign.net

ABSTRACT.

The objective of Springer-Carrier's Corporation in Brazil was to transform their existing facility in Canoas, PortoAllegre into a prototype "Factory of the Future". Carrier's goals were to increase productivity and reduce energy costs while minimizing initial investment costs transforming the factory into a world class facility, showcasing the best technologies and approaches for creating a superior work environment. These objectives were to be achieved by:

▪ implementing superior natural daylighting solutions;
▪ improving indoor air quality;
▪ providing solar driven air conditioning; and
▪ increasing the reliability of electrical power required to efficiently operate the facility.

By implementing this strategy it is to be demonstrated that:

▪ the impact of rapidly rising utility costs can be contained;
▪ the factory owner would be in a positive cash flow situation; and
▪ by addressing energy and productivity, production costs would be greatly reduced.

1. INTRODUCTION.

Springer-Carrier is undertaking the renovation in three phases, with the intent of increasing their employee's productivity as well as obtaining significant energy savings. Daylighting and solar powered cooling systems are the two most significant strategies to be implemented in achieving these goals. Up to date, the first of the three phases has been completed, and consisted of replacing 125,000 square feet of existing roof with a new saw-tooth roof structure that incorporates daylighting, while still allowing for a future incorporation of a solar array system in Phase II that will power an absorption cooling system for the entire factory. The objectives of the first phase were to:

▪ remove the existing roof and skylight system and implement a controlled daylighting system;
▪ integrate a new roofing system with improved insulation and radiant barriers;
▪ implement an absorption cooling system (that will be matched to the proposed Phase II solar systems requirements); and
▪ improve lighting conditions within the factory by adding task lighting and painting the interior with light colors.

The second phase will consist of designing, implementing, and maintaining a solar system that will occupy up to 87,000 square feet of roof area. The proposed system, to be constructed in increments, will be mounted on six sections (north facing) of the new Phase I sawtooth roof. The intended system will utilize Duke Solar's VAC 2000 modules with non-imaging type collectors. The solar tubes will operate at a normal 200º C (392º F) and a pressure of 14.6 bars (212 p.s.i.) The system consists of evacuated tubes that will be assembled in pre-manifolded sections which fit into integrated mounting brackets implemented in Phase I. Once Phase II is completed the solar systems will:

▪ provide the thermal energy necessary to fuel 700 tons of double-effect absorption cooling and
▪ provide up to 200 kiloWatts of electrical power.

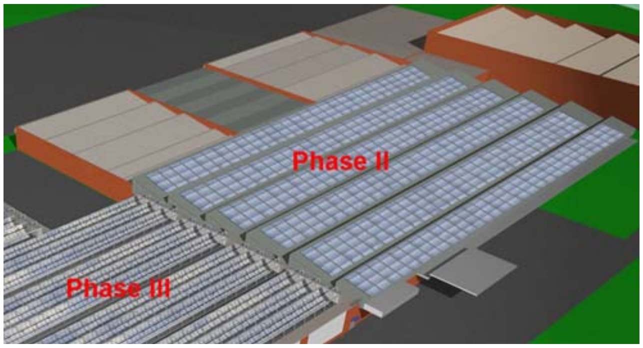

Fig. 1: Rendering of Phase 1 and Phase 2,
Daylight Sawtooth Structure with Solar Tubes.

The third phase will potentially consist of adding 152,940 square feet of Duke Solar's Power Roof system capable of providing 1.2 megawatts of power. The power roof is a unique, high temperature solar system that is a solar collector as well as a weather-tight, well insulated roofing assembly providing excellent daylighting to the space below. The proposed system will consist of 564 modules that are each 12 feet x 16 feet for a total of 108,288 square feet.

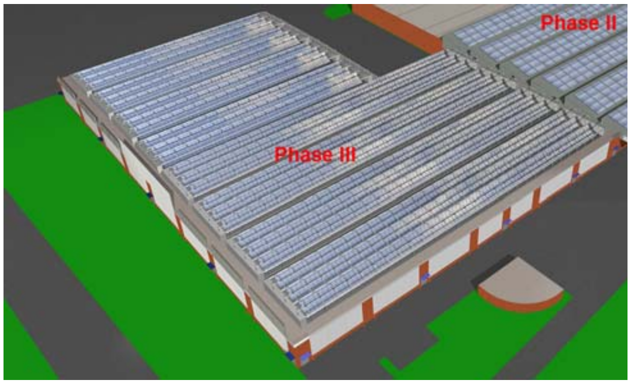

Fig. 2: Rendering of Phase III,
Power Roof Solar Addition.

2. EXISTING CONDITIONS.

Currently, throughout South America as well as the rest of the developing world, the majority of industrial factories are energy-inefficient, highly polluting, and generally provide poor working conditions for their employees. To the factory owner this results in lower productivity and higher utility bills. To the employee the results often translate into poorer attitude and greater health problems. To the community in which the factory is located, it means greater levels of air pollution. It is Springer-Carrier's objective to demonstrate that these problems can be solved through the use of daylighting and solar driven absorption cooling.

Physical Description of Plant and Operation.

The 217,688 square feet (20250 square meter) factory is 492 feet by 443 feet. The 492 feet direction runs east west. Solar access is very good with true north being only several degrees off the building's orientation.

There are 1100 employees of which 600 are working in the production sections of the factory. The factory has two shifts. The first is from 7:30am to 5:00pm. The second, smaller shift, is from 5:00pm to 1:30am.

The interior of the building was well organized and maintained but the interior walls, ceiling surfaces, and structural elements were quite dark. The lighting was provided by suspended fluorescent fixtures and horizontal skylights, which were in extremely poor conditions. The uncontrolled horizontal skylight sections were creating considerable over-heating inside the factory during the warmer months. Other than a few of the office areas, the factory was not currently air-conditioned.
The interior of the building was quite poorly lit. Even during the daytime the light levels in the factory floor ranged from only 10 Footcandles (100 Lux) to 45 Footcandles (450 Lux). The great majority of the factory was at all times under 30 Footcandles (300 Lux).

Fig. 3: Exterior Existing Conditions.


Fig. 4: Interior Existing Conditions.

The plant is powered by electricity, which is provided by the American Energy System (AES), and by a low-grade LP gas. The cost of the lower grade LP gas was $.46/therm. The facility requires approximately 1.14 million kWh per month. During the on-peak time of 6 pm to 9 pm the factory consumes 122,000 kWh and during off-peak it consumes approximately 1,015,000 kWh. The on-peak energy cost is $.23/kWh and the off-peak rate is $.03/kWh.

TABLE 1: ELECTRICAL COST-1998-99.

		Consumption	Rate	Energy Cost
Monthly	On-Peak	122,000 kWh	R$.38/kWh	R$ 45,600
			US$.23/kWh	US$ 28,060
	Off-Peak	1,015,000 kWh	R$.05/kWh	R$ 50,750
			US$.03/kWh	US$ 30,450
	Total	1,137,000 kWh	R$.085/kWh	R$ 96,350
			US$.051/kwh	US$ 58,510
Yearly	On-Peak	1,464,000 kWh	R$.38/kWh	R$ 556,320
			US$.23/kWh	US$ 336,720
	Off-Peak	12,180,000 kWh	R$.05/kWh	R$ 609,000
			US$.03/kWh	US$ 365,400
	Total	13,644,000 kWh	R$.085/kWh	R$ 1,159,740
			US$.051/kWh	US$ 695,844

The cost of the low-grade LP gas is $113/1000 cubic meters or equivalent to $.43/gallon or $.51/therm. However, the Btu content is lower and estimated at 85,000 Btu/gallon versus typical LP gas at 91,000 to 92,000 Btu/gallon. Currently only 6,000 cubic meters of LP gas are used per month (72,000 cubic meters per year).

Energy use Profile.

The factory, in 1998, had a peak consumption in August of 3.4 megaWatts. The average monthly peak is 2.3 megaWatts and the lowest peak consumption was in May with 1.2 megaWatts.

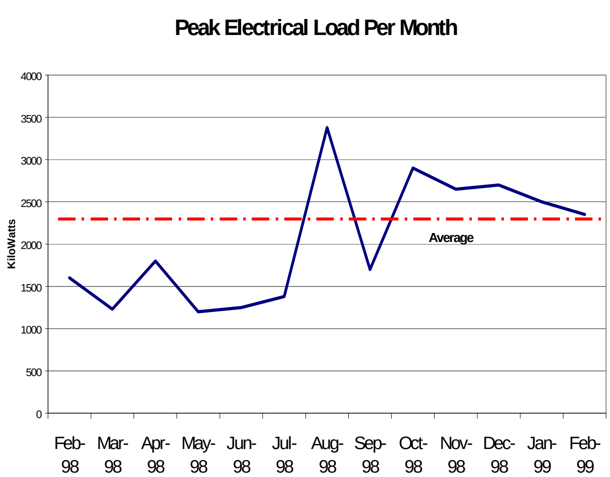

Fig. 5: Peak Electrical Load Per Month Chart.

TABLE 2: DEMAND CHARACTERISTICS.

	Weekend	Weekday				
		1:30am 7:30am	7:30am 5:00pm	5:00pm 6:00pm	6:00pm 9:00pm	9:00pm 1:30am
Minimum Average	0.4	0.9	2.6	2.0	1.5	1.2
Maximum Average	0.6 est.	1.0	2.8	2.7	2.3	2.1
Minimum	0.3	0.6	1.5	1.9	1.2	1.1
Maximum	0.7 est.	1.8	3.4	2.9	2.3	2.3

Energy Inflation.

Currently on peak electricity is $.23/kWh and off-peak electricity is $.03/kWh. If energy costs continue to rise at the same rate they have in Brazil since 1995, by the year 2005 the price of peak power will be $0.53/kWh and off-peak electricity will have risen to $0.07/kWh. Even if this current energy inflation rate of 15% per year can be reduced to 10%, energy costs in the year 2010 will have risen to $0.65/kWh for on-peak and $0.08 for off-peak electricity.

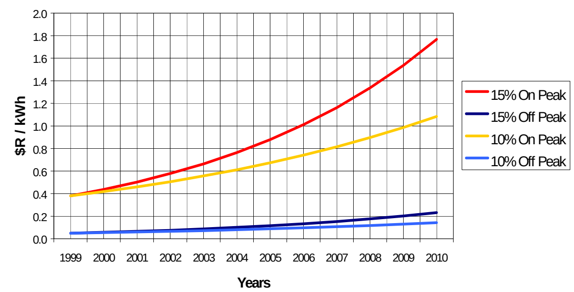

Fig. 6: Electricity Cost Inflation Chart.

3. PHASE I'S DAYLIGHTING STRATEGY.

The goal of Phase's I daylighting strategy was to design a controlled daylighting system capable of lighting at least one-half of the daylight hours of the day. To ensure success daylight sensors were employed, and additionally the floor surfaces, walls, columns and beams were painted to obtain an overall interior building reflectance of 50%.

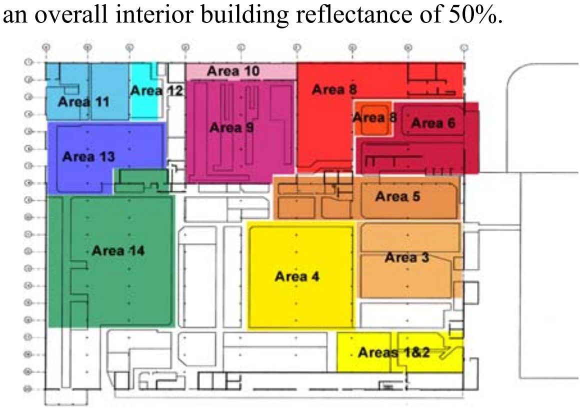

Fig. 7: Plan of Factory by Sectors.

TABLE 3: LIGHT LEVELS BEFORE RENOVATIONS.

Sector	Description	Operation		Lighting Levels (Lux)		
#		Day	Night	Min	Max	Avg.
1	Split Assembly	x	x	300	330	315
2	Split Assembly	x	x	300	330	315
3	RAC Line 1	x	-	240	350	295
4	RAC Assembly	x	x	320	380	350
5	106 Line 2	x	-	280	450	365
6	Self Assembly Line	x	-	150	180	165
7	Coils	x	-	150	150	150
8	CAC Chiller Line	x	-	180	260	220
9	Painting (dropped ceiling)	x	x	180	340	260
10	Mechanical Room	-	-	?	?	?
11	Cooler Assembly	x	-	120	120	120
12	Maintenance	x	x	420	420	420
13	CAC Stamping	x	-	140	180	160
14	RAC/Split Stamping	x	x	100	260	180
	Material Storage	x	x	100	240	170
	Average					**232 Lux**

The daylighting strategy designated produced 50 footcandles (500 Lux) at least half of the time from 7:00am to 5:00pm and 30 Footcandles (300 Lux) at least half of the time. In addition, task lighting over specific equipment or assembly operations was implemented in areas that are frequently used at night. If daylighting was not implemented and even greater amounts of additional lighting (increasing light levels to 40 footcandles) were installed to bring the entire facility up to a reasonable standard, the cost to light and air conditioning would also increase. The Power DOE simulation results for this scenario indicated that the additional estimated cost per year would be $55,467. This yearly cost did not include the first cost of the extra cooling equipment required or of the extra light fixtures needed. It was projected that just the lighting cost to upgrade the factory by 10 footcandles (100 Lux) would require an additional 600 fixtures and be approximately $48,000.

The daylighting strategy consisted of implementing south facing, vertical glazing into a new sawtooth roofing system. The south- facing vertical glazing minimized direct beam radiation from entering the space, and it created a uniform non-glare natural lighting condition. We specified a 6’-3” high, double-glazed Lexan with a high transmission (85%). The clerestory windows run the entire length of the building, and 7% of the total aperture area is mullions.
In order to control the direct beam radiation that comes through the glass very early in the morning and late in the afternoon during the summer months, it was recommended that baffles be mounted perpendicular to the clerestory windows. Because this glare was limited to only a few hours during a couple months of the year, our suggestion was to evaluate the specific situations once the glazing was installed, and then implement the baffles where needed. In the great majority of the factory this was not problematic and the baffles were not necessary. The worst month would be in January when direct beam radiation would enter into the factory from 6:00am to 8:00am and 4:00pm to 6:00pm.

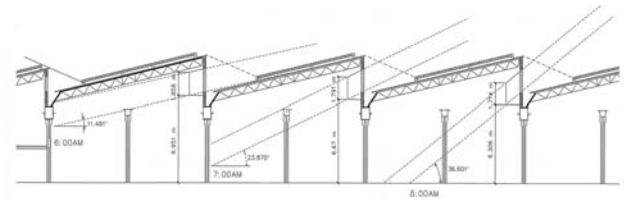

Fig. 8: Section through New Sawtooth Structure.

The daylighting strategy was designed to produce 50 footcandles, at least half the time from 7:00 am to 5:00pm, and 30 Footcandles at least ¾ of the daylit hours. Using the Solarsoft-Daylite analysis programs we analyzed the daylight behavior for a typical section of the factory trying different glazing amounts. Once the optimum glazing amount was established, we were able to produce daylighting schedules, which indicate the amount of supplemental electric light required during the year to reach the desire lighting levels. These extensive schedule were in turn, input into Power DOE to produce a dynamic analysis of how the building performs over the course of the year. The immediately following chart summarizes the daylighting contribution between 7:00am and 5:00pm, with 30 footcandles, 40 footcandles, and 50 footcandles.

TABLE 4: DAYLIGHT CONTRIBUTIONS (7:00-17:00).

	General Location Under Monitor			Lowest Light Level
	300 Lux	400 Lux	500 Lux	300 Lux
Jan	96%	95%	87%	99%
Feb	96%	79%	67%	88%
Mar	89%	64%	51%	67%
Apr	63%	50%	46%	51%
May	50%	37%	25%	26%
Jun	41%	26%	20%	26%
Jul	52%	30%	24%	28%
Aug	59%	49%	34%	47%
Sep	84%	60%	40%	61%
Oct	93%	69%	65%	80%
Nov	97%	96%	68%	100%
Dec	99%	95%	79%	100%
Average	**77%**	**63%**	**51%**	**64%**

In order to evaluate the daylighting conditions at different times of the day, Radiance was used to simulate a sectional model of the factory by which glazing amounts and wall reflectances were tested.

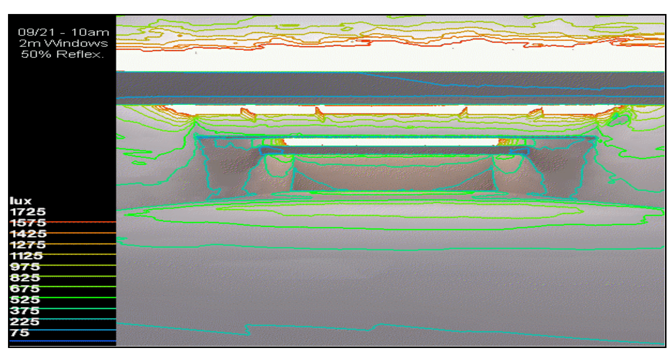

Fig. 9: Radiance Daylight Simulation. Sept 21, 10:00am.

Finally, in order to enhance the daylighting strategy, it was recommended that certain elements be repainted as an integral part of the renovation in Phase I. Structural beams, walls and columns should be painted white (semi-gloss white paint 70% reflectance). Wherever practical the floor should be painted light green (53% reflectance) to medium blue (49% reflectance).

4. PHASE'S I INSTALLATION OF AIR CONDITIONING.

Well recognized is the relationship between productivity and the temperature and humidity of the workplace. Most factories in Brazil are not air conditioned, despite indoor air temperatures often exceeding 37º C (98º F). Productivity certainly suffers in such working conditions. Brazilian law also mandates a maximum temperature for workers. Many factories are in violation of this requirement and the motivation for enforcement is now increasing. This initiative is intended to demonstrate how these issues can be dealt with cost-effectively.
The second component of phase I was to install the absorption cooling equipment that in phase II will be powered by solar energy. The objective was to implement air conditioning throughout key occupied areas within the factory, install air filtration and fresh air make up systems, and install absorption cooling equipment that would eventually be powered by solar energy.

The initial analysis conducted by Carrier indicated that the factory would require a 1000-ton unit of cooling.

TABLE 5: AIR CONDITION TONNAGE BY BUILDING SECTORS.

Sector	Description	Preliminary Tonnage Required
1	Split Assembly	126
2	Split Assembly	
3	RAC Line 1	
5	106 Line 2	
4	RAC Assembly	120
6	Self Assembly Line	134
7	Coils	
8	CAC Chiller Line	
9	Painting (dropped ceiling)	108
10	Mechanical Room	
11	Cooler Assembly	89
12	Maintenance	
13	CAC Stamping	
14	RAC/Split Stamping	126
	Material Storage	62
	Offices	100
	Room 218	70
	Total	**935 Ton**

The typical cost per ton for an industrial air conditioning system was approximately $1,800/ton. The total cost for a 1000 ton air cooled chiller would have been $1,800,000. However, with the daylighting, radiant barriers, painting recommendations, and lighting recommendations the estimated peak load dropped by a consistent 250 tons. This equated to a first cost reduction in cooling equipment of $450,000.

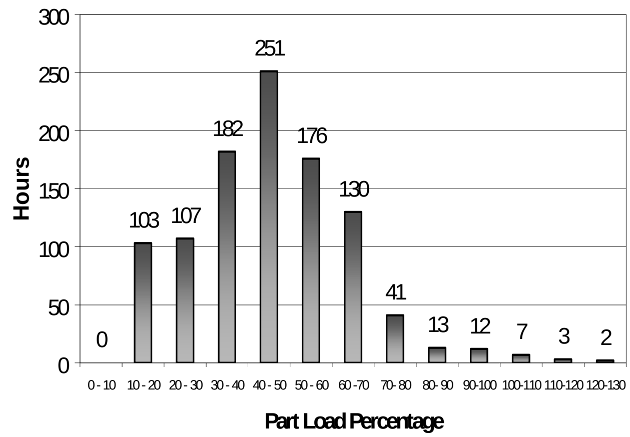

Fig. 10: Springer-Carrier Chiler Load Profile (700 ton Load).

The following load profile on a 700-ton absorption unit, shows that the load is exceeded only 12 hours during the course of an average year.

5. PROJECTED COSTS AND SAVINGS.

As manufacturing processes improve, energy costs are becoming a greater percentage of the overall product cost. Because of the uncertainty of future energy costs, energy efficiency is becoming an increase priority. Since 1995 electricity prices in Sao Paulo have risen 73%. In the month of July and August of 1998 the average cost of electricity in Brazil had gone up over 11% while in Sao Paulo prices have increased a staggering 21%. To compete in the coming years, the "Factory of the Future" will need to be energy efficient.

Daylighting Savings.

By implementing the daylighting strategy it was estimated that $450,000 would be saved by reducing the cooling equipment by 250 tons, and $48,000 would be saved by reducing the amount of electrical lighting that would have to be upgraded. In this way the total initial capital cost savings amounted to $498,000 in the first year.

Productivity advantages.

Currently 600 workers work in the factory areas to be renovated. By air conditioning the factory and introducing daylighting it is most likely that important productivity gains will occur. If these productivity gains are even a fraction of those experienced in other documented cases, the savings to management will be significant and the health of the workers improved. If productivity gains were approximately 1/3 of those experienced at daylit schools in North Carolina, and ¼ to a 1/5 of those obtained in California's daylit schools, the increase in performance would be 5%. If the impact of introducing better quality air is only 1/3 that of what the US Environmental Protection Agency projects that could be achieved by reducing indoor air quality issues, another 1% in productivity could be realized. Currently the labor costs associated with the employees working in the factory are $1,983,529 per year. A 6% improvement in efficiency would result in first year savings for Springer-Carrier of $119,000 over. If general inflation continues to increase at 10% per year and worker salaries keep pace with inflation, the value of these productivity gains in 2005 will have risen to $191,649 and by 2010 it will have reached $308,650 annually.

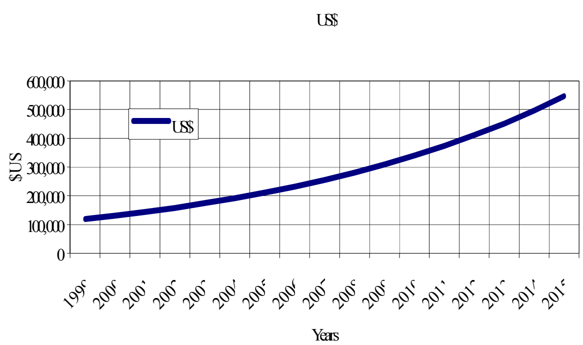

Fig. 11: Value of Projected Productivity Gains (10% inflation).

Total Savings.

The total cost for implementing daylighting and absorption cooling for the facility was $1,200,000. To this total costs we need to subtract $450,000 in order to account for a 250 ton reduction in equipment due to the enacted recommendations. Also $48,000 need to be subtracted from the total cost due to savings towards upgrading the electric lighting. After accounting for the total initial capital cost savings ($498,000) the total cost for implementing daylighting and absorption cooling is $702,000.

TABLE 6: TOTAL COST SAVINGS.

YEAR	10% Productivity Gains	10% Energy Savings	Toatal Savings	Accumulative Savings
2000	$119,000	$55,467	$174,467	$174,467
2001	$130,900	$61,013	$191,913	$366,380
2002	$143,990	$67,114	$217,104	$577,484
2003	$158,389	$73,825	$232,214	**$809,698**
2004	$174,227	$81,207	$255,434	$1,065,132
2005	$191,649	$89,327	$280,976	$1,346,108
2006	$210,813	$98,259	$309,072	$1,655,180
2007	$231,894	$108,084	$339,978	$1,995,158
2008	$255,083	$118,892	$373,975	$2,369,133
2009	$280,591	$130,781	$411,372	$2,780,505
2010	$308,650	$143,859	$452,509	$3,233,014
2011	$339,515	$158,244	$497,759	$3,730,773
2012	$373,466	$174,068	$547,534	$4,278,307
2013	$410,812	$191,474	$602,286	$4,880,593
2014	$451,893	$210,621	$662,514	$5,543,107
2015	**$497,082**	**$231,683**	**$728,765**	**$6,271,872**

The total investment cost of $702,000 would be recuperated after three and a half years if we account for productivity gains and energy savings within a 10% inflation rate.