The Use Of Daylight In The Design Of A Controlled Environment For Food Production In The Caribbean And Other Equatorial Climates

by
Curtis B. Charles
B.Arch., Howard University School of Architecture
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Signature of Author
Curtis B. Charles, Department of Architecture, 12th., May 1989

Certified by
Timothy Johnson, Principal Research Associate, Thesis Supervisor

Accepted by
Julian Beinart, Chairman, Departmental Committee for Graduate Students

To my wife Karen,
And
our daughter Khadijah,
for their Love, Patience and Support
throughout my Tenure at M.I.T.

And
My deepest appreciation to
La Foret Engineering Co., Japan; The Cabot Fund, M.I.T.;
The American Institute of Architects;
and M.I.T.'s Department of Architecture
For their
Financial and Technical support of this Thesis.

Last but not Least
to everyone whoever believed in me
And
gave me a chance
to do
my best.

THANK YOU!

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Submitted to the Department of Architecture on May 12th., 1989
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ABSTRACT

This thesis addresses the use of daylight in the design of a controlled environment for food production in the Caribbean and other Equatorial climates. An expanding population has put a tremendous burden on the food production industry in these climates. The increasing population in these climates means that existing fertile land is being taken-over for housing and infrastructure. Furthermore, the fishing industry is also a victim of over-fishing due to a need for alternative foods.This design proposes a technological solution to this social problem. Presented is one answer to improve the fishing industry, through a controlled environment for intensive aquaculture production. To improve crop production due to depleting fertile land and flooding, this thesis proposes hydroponic cultures in multi-stories. In addition, the success of this farming complex is dependent on appropriate research by staffed scientists, seeking to continually improve the end products of this facility. Within this ecosystem, far greater yields will be attained than traditional forms of agriculture, and, aquaculture.

The challenge here is to present the most economic solution. As a result, the design of this facility is based on a three-level hydroponic (crops growing in a nutrient solution) facility, a fish hatchery, indoor fish ponds, and, research laboratories within the aquaculture and hydroponic facilities. This thesis presents two design solutions : one on land, that addresses the issues of flooding and a depletion of available fertile land, and one at sea, that addresses a time in which the population has grown to such a degree that food production at sea becomes an economic reality.

There are many ways to introduce natural daylight into this proposed farming complex. Intensive research has indicated that these methods can often range from the very simplistic to the very intricate, as displayed in new emerging technologies such as the Himawari system developed by La Foret Engineering, of Japan. However, the following are techniques that will be applied in this thesis to bring daylight into the buildings of this proposed farming complex :

1. Optical lighting Himawari system)
2. Perimeter lighting
3. Reflective lighting
4. Top/Core lighting

Research has indicated that even during the rainy season (July to December) - in some of these equatorial climates - there is adequate available diffused sunlight to reach the crops and aquatic life within this proposed controlled environment.

This thesis also addresses the energy and cooling load requirements that result from the use of daylighting. Once again the most economic design is presented in this case study. However, the resulting economic solution (to meet the cooling loads) that is presented for the proposed site in Trinidad, may not be the most desirable solution for other equatorial climates. Consequently, wind energy, solar energy, co-generation, and traditional electricity, are all analyzed.

Thesis Supervisor : Timothy Johnson
Title : Principal Research Associate

CHAPTER 1 :

THE PROBLEM

Over the last ten years the agriculture and fishing industry in the Caribbean has experienced an alarming decline. This problem has had a severe negative impact on the Caribbean's economic development. However, nutritional and health problems such as: malnutrition, undernutrition, and nutrition-related diseases have been the more immediate consequences of a declining agriculture and fishing industry.

According to the document 'Regional Food And Nutrition Strategy,'[1] between 29 and 75% of the families in the Caribbean do not obtain an adequate supply of food. Furthermore, the food they do receive does not satisfy protein, calcium, and iron needs. This results in an average infant morbidity rate of twice that of North America, and a death rate among children aged 1 to 4 years of five times that of North America. Those families that receive protein in their diet, consume almost 90% imported protein. Even where the direct source of protein is currently produced in the Caribbean - poultry, pigs, cattle production - the major inputs into the production of these commodities, i.e. feeds (particularly protein inputs), are imported.

The rapid decline in the agriculture and aquaculture industries in the Caribbean can be attributed to political, social, and environmental dilemma.

Politically, very few governments in the Caribbean have enacted and sustained viable policies to assure steady growth of the agriculture and aquaculture industries. There has been insufficient research and very little technical innovation. Socially, the past decade has shown a decline in the entering labor force of the agricultural industry. The young people are refusing to adopt agriculture as a profession . The average age of the farmers is now above 60 years. These factors are major contributors to the declining production and productivity of agriculture.

Environmentally, many Caribbean islands and other equatorial countries such as Sudan, and Ethiopia have been experiencing very long periods of droughts. The result has been the displacement of available water, damage and destruction of field crops, an alteration of the crop growing season, and an increase in the number of extremely hot days. Some scientist have stated that this phenomenon may be a result of rising trace gas concentrations for carbon dioxide, nitrous oxide, methane, and chlorofluorocarbon. [2]

Another hindrance to the agricultural and aquacultural industries, has been the effect of the climatic conditions. The tropical climate of the Caribbean is divided into the sunny season (January to May) and the rainy season (June to December). Most farmers sow their crops in the sunny season, and harvest during the rainy season. For as long as farmers have practiced agriculture, traditional forms of agriculture have been at the mercy of the rainy season, and a solution has yet to be reached. On June 6th. 1979, the meteorology station of the island of Trinidad and Tobago announced a record rainfall of 5.5 inches. Everywhere throughout the island was completely submerged by flood waters and debris.

The Flood Committee, established by the Ministry of Food Production and Marine Exploration, reported that the crops that suffered the greatest losses included: 131 acres of tomato, 122 acres of cabbage, 21 acres of bodi, 21 acres of sweet pepper, 36 acres of cucumbers, 16 acres of cauliflower, 32 acres of eggplant, and 21 acres of okra. It was estimated that compensation in the sum of $5,856,258.77 (1979 Trinidad dollars), was to be divided among 347 farmers, for losses incurred.[3] Unfortunately, this scenario is not an isolated one. Each year during the rainy season, and, throughout the Caribbean, production and productivity of the agricultural and aquacultural industries are paralyzed or adversely affected, due to severe floodings.

Additionally, recent trends have shown that due to the increasing population growth of the Caribbean islands, there is a very strong probability that present fertile land, (which is increasingly being used for housing) will sharply decrease. The depletion of fertile land will then led to a decrease in crop land, which will result in a decrease in crop food production and cattle growth. Also indirectly affected will be a fish food due to over-fishing. This thesis attempts to use modern technology to present a solution that will improve the agriculture and aquaculture industries. (fig. 1a)

In an attempt to address the need to grow enough food to meet the nutritional needs of an expanding population, and the problems encountered by the agriculture industry during the rainy season, farmers began to practice hydroponics (the technology for growing crops in a nutrient solution, with or without the support of an inert material to provide artificial support.) About four years ago this trend began to manifest itself in Trinidad and Tobago. These farmers received large sums of money in the form of loans from the Agricultural Development Bank (ADB).

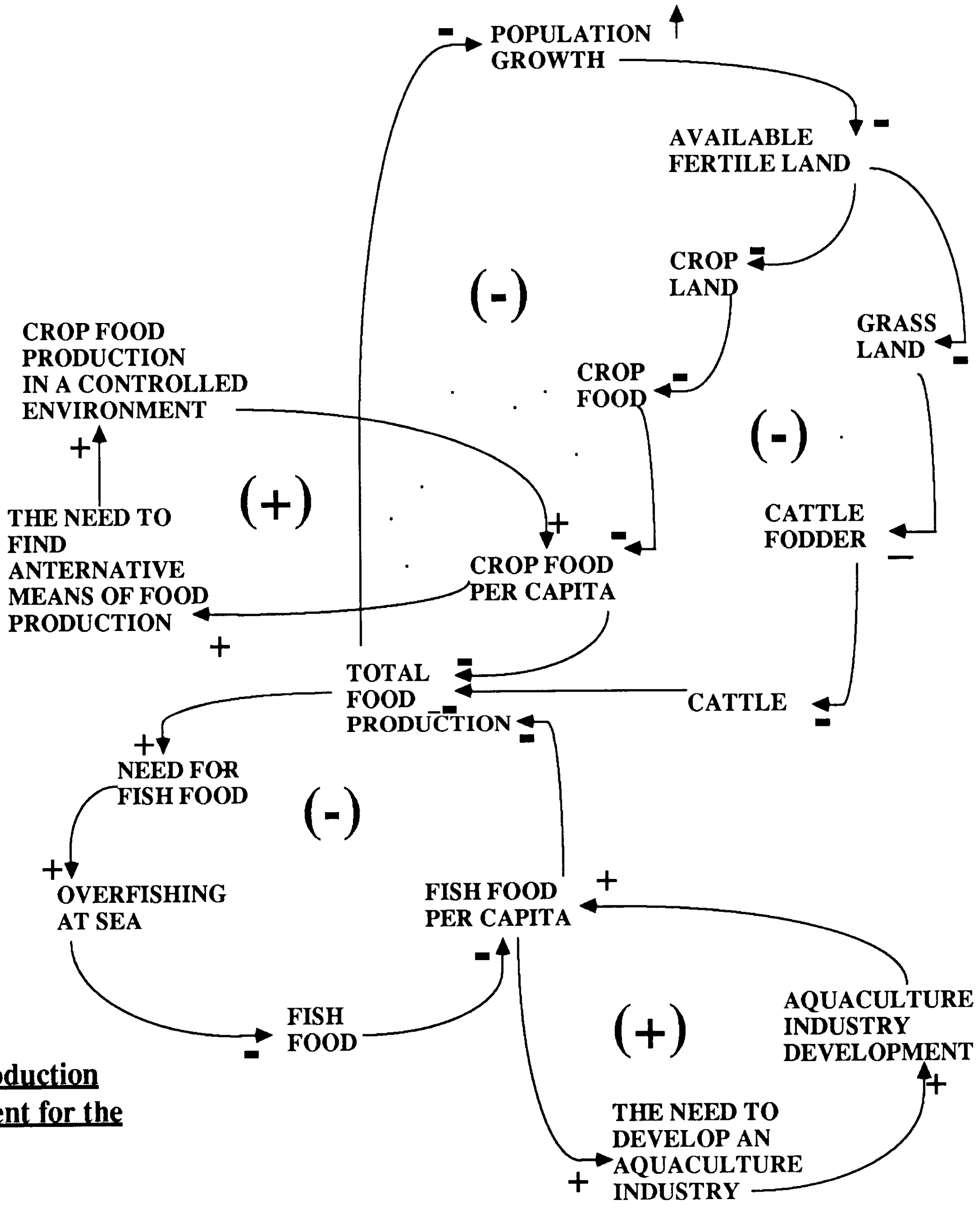


Figure 1a.
Flow Diagram of Food Production in a Controlled Environment for the Caribbean Food Matrix

However, the officers of the ADB neither properly screened the farmers to make sure that the farmers possessed the scientific, and, managerial background, nor, did the officers properly researched the availability of raw materials needed for the continued success of hydroponic culture. As a result of the failures of the officers of the Agricultural Development Bank, the hydroponic experiment was a disaster and the government lost the money it invested in this program. A report by the Ministry of Agriculture stipulated three major reasons why the practice of hydroponics failed in this program :

1. Most farmers involved in the practice of hydroponics lacked the scientific and technical background in agricultural chemistry, and plant physiology, required to monitor the system efficiently.
2. Delays and difficulties in obtaining parts and supplies such as materials for greenhouse construction and auxiliary equipment, like tanks, meters, etc...
3. The initial start-up cost encouraged farmers to grow relatively high-priced vegetables, in order to realize quick returns on their investment.

In order to improve food production in the agricultural and aquacultural industries, development efforts in the Caribbean must emphasize policies to "rapidly" improve production performance. "Large increase in investments" accompanied by appropriate policies and effective programs to improve production performance will be required.[1] The time has come for the Caribbean to address its declining agricultural industry in order to adequately meet the needs of its growing population.

This thesis presents a controlled environment for food production which could very well be one of the answers to the Caribbean's declining food production industry. This thesis proposes a prototype that can be built anywhere in the Caribbean, and, other equatorial climates.

Within this ecosystem, far greater yields will be attained than with traditional forms of agriculture and aquaculture.

The focus of this thesis is to show how an energy efficient structure can be designed with the use of available daylight to supply photosynthetic active radiation to crops and aquatic life. This thesis will show how daylight can be introduced into the plant growth environments using the following techniques :

1. Optical lighting (Himawari system) — includes the use of fiber optics that pipes sunlight - free of any infrared or ultraviolet radiation.
2. Perimeter lighting — involves the size and placement of Lo_Emissivity windows which are being used to minimize the heat content of the entering light.
3. Reflective lighting — includes the use of white quartz gravel, light shelves on the perimeter of the building, and white reflective surfaces on the inside of the building. This technique allows daylight to penetrate deep into the building.
4. Top/Core lighting — involves the use of skylights and atriums.

The concept of this thesis is to integrate hydroponics, aquaculture, live-stock, and energy. In the Aquaculture facility, the Himawari System will pipe sunlight to an algae colony at the bottom of each fish pond. Waste from the fish will filter into the algae colony. The algae will then produce oxygen for the fish. At harvest, the mature algae will be fed to biogas digesters to produce supplemental energy to run the facility. The idea is to find a use for everything; find a use for every inch of space, and waste product, making the facility independent and self-sufficient.[4] However, the task ahead, is to develop this concept into an architecture that represents an alternative solution that will improve the present agriculture and aquaculture industries in the Caribbean, and other Equatorial climates.

CHAPTER 2 :

ENVIRONMENTAL PARAMETERS

In the natural environment some farmers plant crops while others tend to fish production in ponds and troughs. Some farmers even practice the integration of fish with plants and terrestrial systems. Whether we recognize it or not, these farmers are controlling the environment in order to perform their aquaculture or agriculture duties efficiently. In the case of agriculture, farmers must first clear the land of any undesirable natural organisms. They must then till the soil, sow seeds, provide irrigation and manure to improve the crops longevity until harvest time. On the other hand, farmers who practice aquaculture will have to alter the land by first digging a cavity in the earth, and the apply masonry to construct the needed fish pond. All theses techniques are use by farmers to control the environment in order to secure a profitable end product.

Some farmers have literally taken the concept of a controlled environment for their crops and fish production to a much higher level. Farmers have realized that both crops and fish can be grown year-round if grown in greenhouses. Year-round crop production in greenhouses has been quite profitable for some farmers. However, although the cost of crop production has deterred controlled-environment agriculture from becoming a superior alternative to open-field agriculture, yield rate of crops grown in controlled environments is often greater than that of field crops.[5]

Some scientists have reported full grown lettuce and other salad greens in 33 days.[6] Others reported full grown lettuce in as little as 22 day.[7] This is almost two to two and a half times less the growth rate of approximately sixty days in open field. Yet another example is that which was displayed at the Tsukuba Expo, Japan, 1985 : One tomato plant, 3ft tall, 30ft wide with its roots submerged in a nutrient solution tank, bore 12,000 tomatos over a twelve month period.[8] One very common element of the above plant growth examples is that they were all grown in single-story greenhouses.

This thesis has taken food production in a controlled environment a step further by presenting a multi-story crop production facility. This is a design solution for the Caribbean and other Equatorial climates where an exploding population has drastically decreased the availability of fertile land. Also, in these climates natural disasters such as flooding, droughts and hurricane are annual perils to the food production industry. The ideal design solution to improve and better the food production industry is one in which the design integrates all the elements of the climate. This thesis presents a multi-story food producing environment in which the humidity, light, and temperature will be controlled.

TEMPERATURE

The biochemical and physiological reactions in plants are greatly dependent on the effect of temperature changes. Small changes, for a long period, in the designed temperatures may slower or even abort photosynthesis. The optimum temperature range for plant growth may be quite different from the requirements for seedling growth. In addition, even different temperature ranges may occur for fruit and leaf development or flowering. Temperature is the one critical environmental factor which greatly affects flowering. Many vegetables are induced to flower by low temperatures.

Tomatos will produce more flowers if grown at 80^0 F during the day and 65^0 F at night.[9] For optimum plant growth it is imperative that the temperature during the light period be different from the temperature during the dark period. This temperature differential for day and night plant growth also varies according to the plant species. However, optimum temperature regimes have been reported for only a few plant species.[10] The available literature that group plants in optimum temperature ranges for successful growth, can only be used as a guide. What we do know is that temperature in a plant growth environment fluctuates with the manipulation of CO2, the intensity of light and humidity control.

HUMIDITY

Humidity is described as, the amount of water vapor in the air. In most instances humidity is expressed as *relative humidity* , wiich is characterized as the ratio of the amount of water vapor present in the air to the maximum amount that can be present under the same condition.

Either very low or very high humidity in a plant growth environment could be a detriment to crops by making plants more prone to diseases. High humidity may reduce the translocation of ions to shoots because of reduced transpiration. Furthermore, as humidity increases and transpirational cooling decreases, heat loss from leaves by conduction and convection becomes important and air movement across the leaves becomes vital.[11] At low humidities a water stress may occur as transpiration increases ... severely reducing growth and fruit production.[10] Many crop scientist have agreed that a humidity range between 50% RH and 70% RH is satisfactory for optimum plant growth.[9]

LIGHT

Perhaps the most important element of plant growth is light, for no form of life is possible without the energy of light. However important, there has been much confusion about the term “light” in the field of horticulture.

McFarlen has stated that the term "light is improper since light defines the electromagnet radiation sensed by human vision".[12] Some scientists have noted that photosynthetic active radiation (radiation in the 400 - 700 nm waveband — the photosynthesis range) is the accepted quantity for use in plant growth lighting design.[13] Yet others have stated that quantum quantities (micro moles per second per minute) may be used in plant growth lighting.[14] Many different terms are being used to describe light for plant growth. However, the selection of terms and use, depends on discipline, location (indoors or outdoors), traditions, and bias of the reporter, audience, and nature of the publication.[14] During the presentation of this thesis the term light will be used interchangably with photosynthetic active radiation for the following reasons :

1. Although the Lo_E's transmission of energy in the red region is somewhat weakened, the Lo_E glazing will transmit solar radiation at 400 - 700 nm which has the same range of wavelength used by photosynthetic active radiation.
2. This is not a plant physiology thesis. This is an architectural thesis in which the objective is to design an economically feasible controlled environment for crop growth. It is not the intention of this thesis to determine all the crops that will be grown in this facility, but rather study andunderstand green crops and their response to temperature, humidity, and light. Then, design an environment, based on the manipulation of daylight in which far greater yields will be obtained, than traditional forms of agriculture.

For simplification purposes light will be expressed in foot candle or lux. When expressed in lux it is very simple to convert photometric to quantum light units of measure. For sunlight lux is divided by a constant '54' ; for blue sky divide by a constant '52,' to convert to micro moles per second per meter.[14]

CHAPTER 3 :

CONCEPTUAL & SCHEMATIC DESIGN DEVELOPMENT

During the first stages of the concept development and schematic designs, the idea was to find a lighting technique that will supply photosynthetic active radiation to plants in a multi-story controlled environment. At that time fiber optics was investigated as the primary source of lighting for plants in the multi-story controlled environment. This research led to La Foret Engineering Company of Japan, who is the inventor of this light transmitting technology called “The Himawari System,” (fig. 3a).

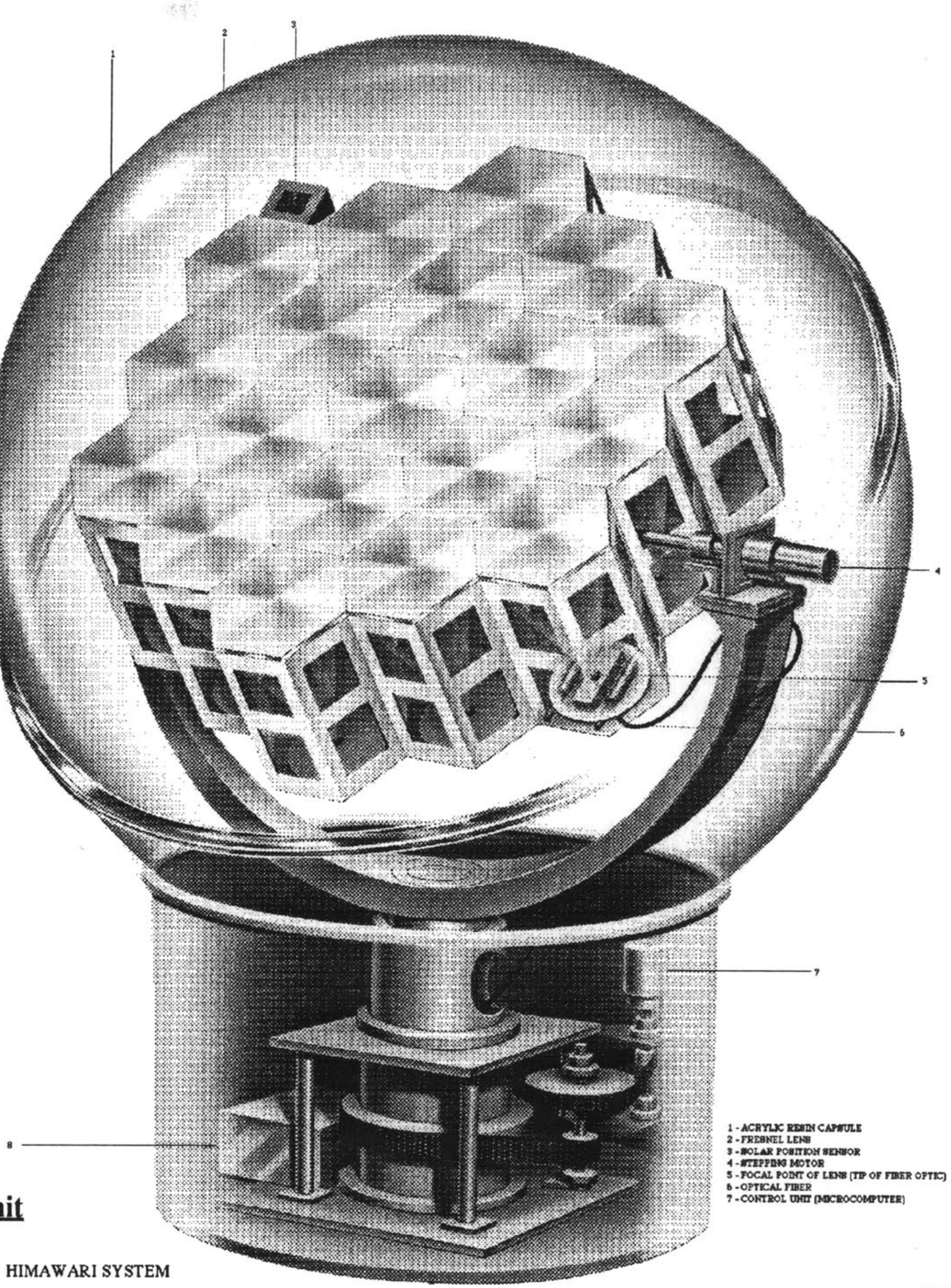
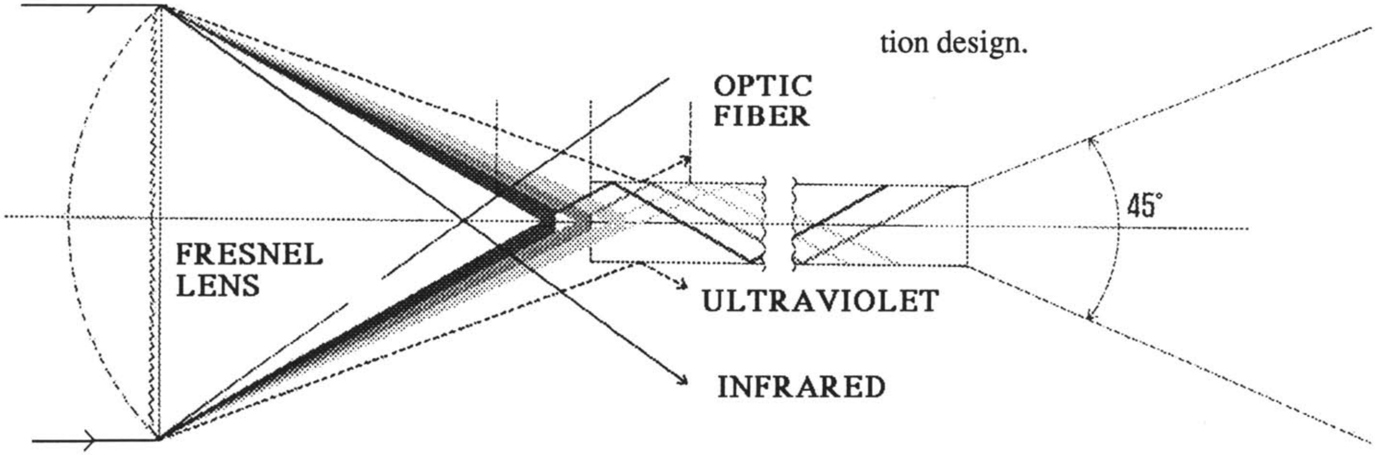


Figure 3a : D-200/L19 Himawari Unit

According to La Foret engineering, each unit admits sunlight — free of infrared and ultraviolet rays — through a protective, transparent acrylic globe. The incoming parallel rays admitted onto an array of fresnel lens are then condensed by a factor of 10,000 onto the focal point of each lens. Positioned at the end of each focal point is the input end of a light conducting optic fiber (fig. 3b). The well polished end of each fiber admits sunlight which is then transmitted by repeated reflection until the other extremity of the fiber optic is reached.

The cool light delivered at the other extremity of the optic fiber cable was a major determining factor in considering this technology. Its versatility meant that crops grown in this proposed controlled environment, where temperature, humidity, and light quality and quantity are controlled, will grow and flourish much better when compared to plants grown outdoors. The important factor here is that the Himawari System can deliver a light quality stripped of ultraviolet and infrared rays, which alters the growth of plants. The use of fiber optic cables by the Himawari system is so necessary for accelerated plant growth that the system immediately became the logical choice for a flexible light distribution design.



Fifure3b : Section Thru. Lens & Optic Fiber.

The Himawari System is equipped with an accurate tracking device to follow the path of the sun, and constantly direct the collecting lens towards the sun at all hours of the day. The Himawari System is also supplemented with energy efficient electric lighting during periods of cloudy weather, overcast skies, or at night time to extend the day length of plants.

This technology has paved the way for me to investigate a whole new field of research : " The Use of Daylight in the Design of a Multi-story Controlled Environment for Food Production." It meant that these facilities could be constructed on very restricted sites, irrespective of orientation towards the sun. This will present an alternative means of food production for people living in the Caribbean and other Equatorial climates who have border-line agriculture and aquaculture industries due to infertile land, flooding, or droughts. In some of these overpopulated cities the Himawari can pipe sunlight to the top floors of office buildings where crops can be grown. Food production in a city, whether at the top floors of office buildings or in a facility such as the one being presented, means that the cost of transportation and storing of products will be drastically reduced. The market is taken to the consumer.

The task then was to develop conceptual and schematic architectural designs that utilized the technology of the Himawari System which would pipe sunlight to plant and aquatic life. It was very important for the architecture to represent an integration of agriculture and aquaculture — a process not normally practiced in traditional field cultures. The objective was to present an architectural solution that would achieve a consistent flow of people, products and information from the research facility to the hydroponic and aquaculture environments. There was also a need for sub-connections within the aquaculture and plant growth facilities. Consequently, all the buildings of this farming complex were to be physically connected (fig. 3c).

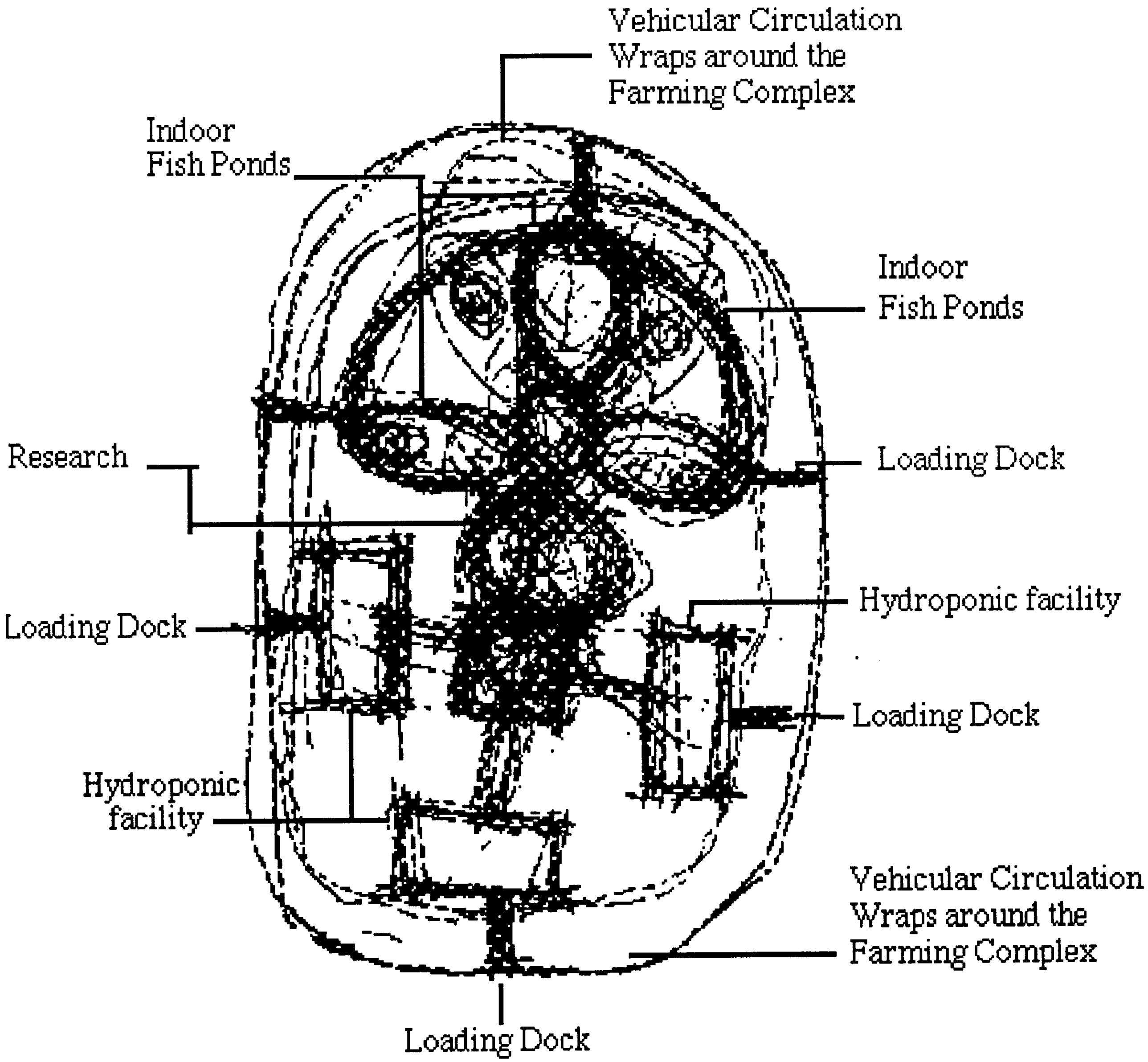


Figure 3c : Schematic Site Development

It was important that the research facility take its rightful place as a beacon of control — the control tower of this farming complex. So, being the brain of this complex the research facility was physically situated at the center. Its primary function being to make sure that each component of the farming complex work in harmony to maximize production. Hence, the design dictated that the aquaculture environment be situated at one end of the research facility, and the hydroponic facility be placed at the other end.

As the design layout developed, a very strong axial design began to take form (fig. 3d).

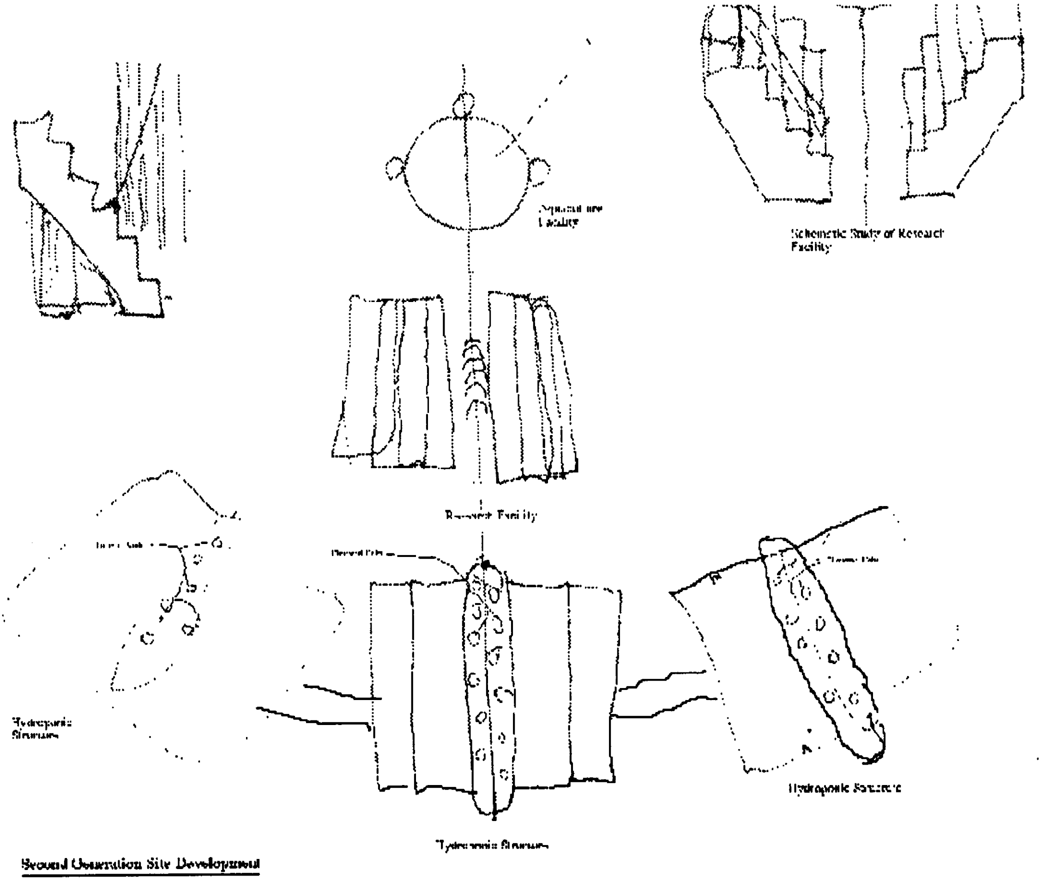


Figure 3d : Second Generation Site Development

The flexibility of the Himawari's technology allowed the design to develop into very interesting geometric forms that unified the site layout (fig. 3e). Architectural elements such as the transparent connectors that radiate from the research facility reinforce the unification of plant culture, fish culture and the necessity of research. The very strong forms that manifested themselves are solely the expression of the functions within each building. This site configuration resulted in three hydroponic structures — two on a 45^0 axis, and the other on a normal axis. Since the Himawari units have the capability to track the sun, solar orientation was not an issue in the site layout design. However, it was mandatory that the hydroponic buildings be placed in such a manner that none will shade the other — the Himawari units will not function if shaded.

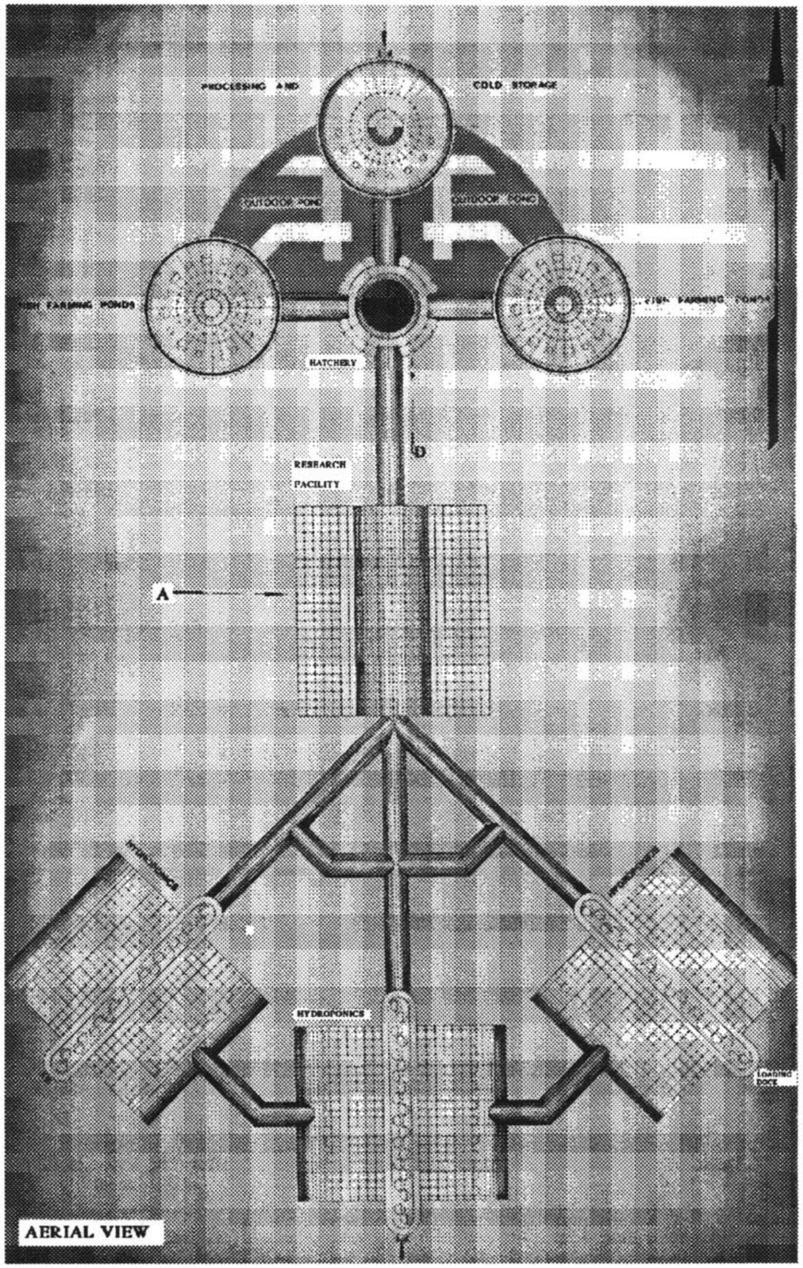
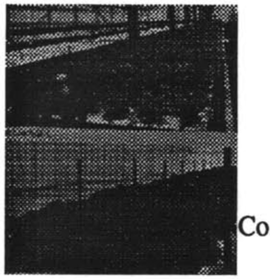


Figure 3e : Final Schematic Site Layout

While developing the design of the hydroponic facility it was decided that the form of the building will follow the function of what happens inside of the structure. Hence, the resulting exterior architecture is a reflection of the four types of proposed hydroponic cultures. The ground floor was reserved for very large plants that grow on tendrils with their roots submerged in a nutrient solution (fig. 3f). The first floor proposed the integration of fish and plant culture in long troughs (fig. 3g). In this unique plant culture, the hydroponics serv as the water quality control for the fish culture. Conversely, the waste from the fish provides rich nutrients for the plants floating on styrofoam.[15] The second floor introduced a *stair-like* system in which the nutrient solution is pumped to the highest growing trough, and then terraces to each consecutive trough (fig. 3h). Finally, the concept of tower hydroponics is one in which plants grow in a tower, on a conveyor system (fig. 3i). The concept here is to show what is possible when very little land is available for food production. In this culture the plants receive photosynthetic active radiation as they pass by the output ends of the optic fibers. The system is also designed so that each growing trough is partially submerged in the nutrient solution tank at the base of the conveyor. The exterior architecture of the hydroponic facility is a reflection of each different hydroponic culture (fig. 3j & 3k).



Co. Ltd

Source: Kyowa Co. Ltd.

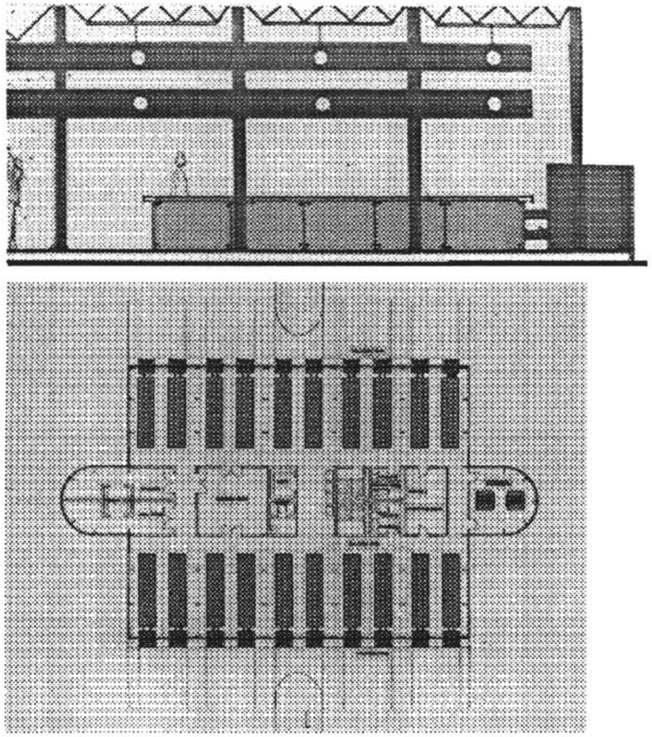


Figure 3f : Schematic Ground Floor Plan & Section

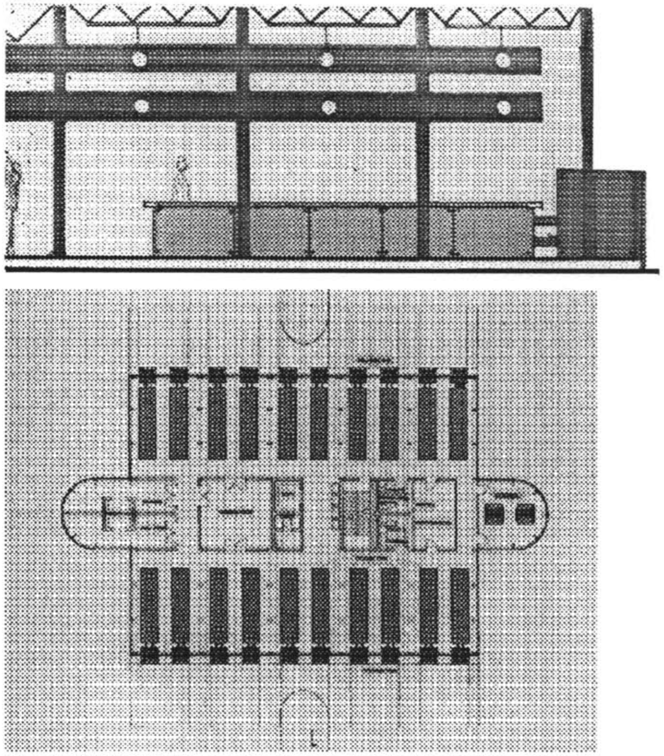


Figure 3g : Schematic First Floor Plan & Section

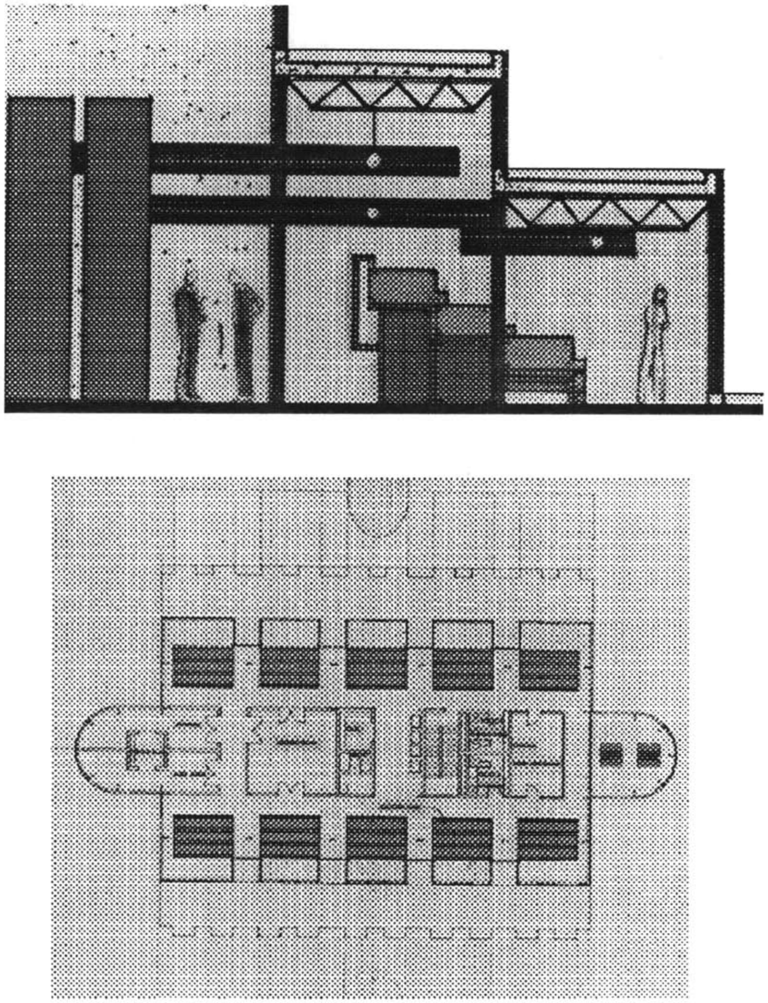


Figure 3h : Schematic Second Floor Plan & Section

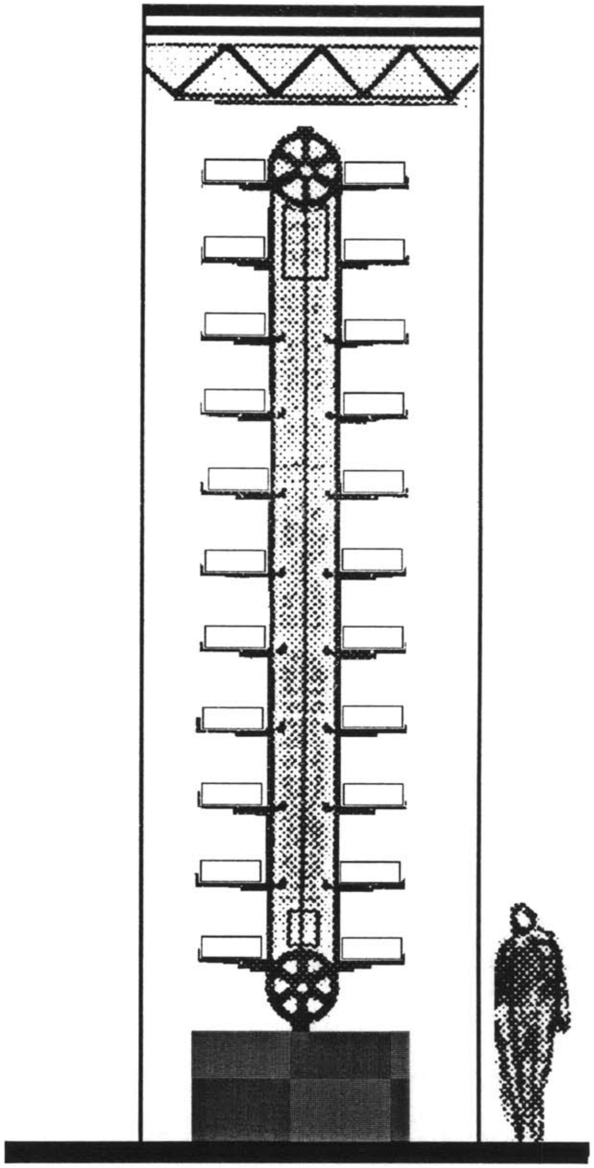


Figure 3i : Schematic Design of Tower Hydroponics

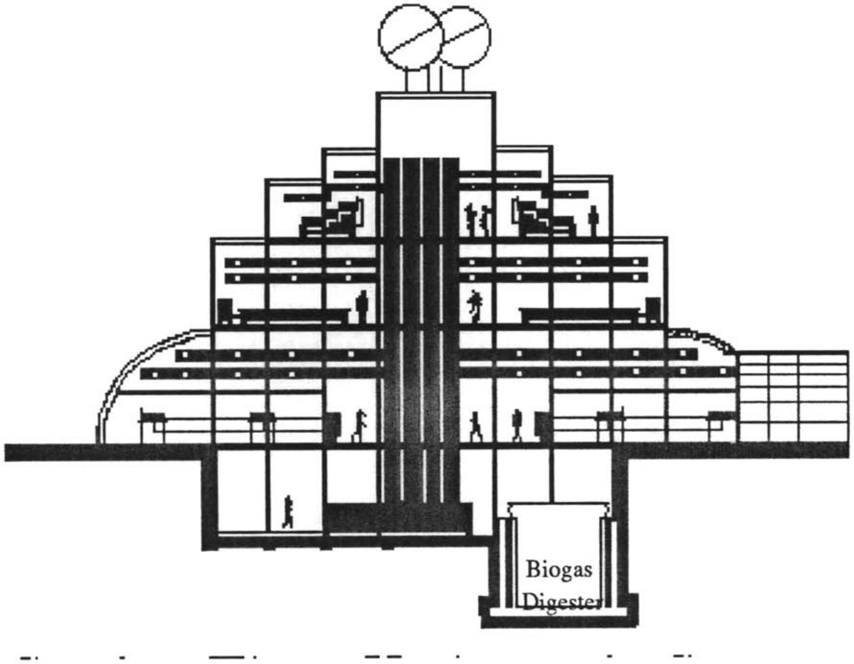


Figure 3j : Schematic Section Thru. Plant Growth Environment

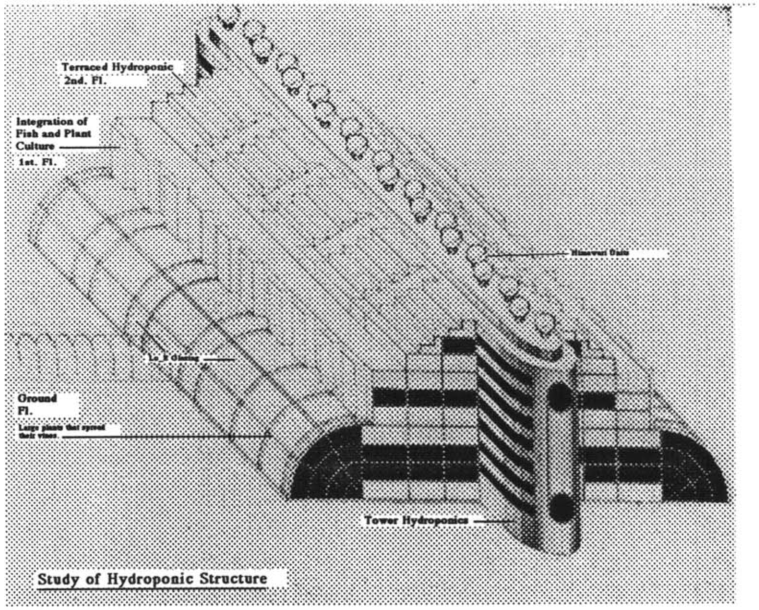


Figure 3k : Schematic Design of Plant Growth Environment

The other component of the final schematic site layout was the aquaculture facility (will be fully discussed later). The hatchery in the aquaculture facility validated the global concept of having a central point of control. This aquaculture facility was based on a design in which fish eggs go through an incubation stage within the controlled environment of the hatchery. When mature they are moved to the controlled environment fish ponds. Once there, they are placed in the sack-fry ponds, rearing ponds, and then outside to the outdoor fish ponds (in that order). Those fish grown solely for spawning purposes are placed in spawning ponds to repeat the cycle. This cycle of fish eggs to full grown fish, and back to eggs, manifested itself in the circular architecture of the fish ponds. (fig. 3L). The resulting aquaculture facility is a combination of two controlled environment fish ponds, a cold storage facility, outdoor fish ponds for the mature fish, and a hatchery which is physically connected to the research facility.

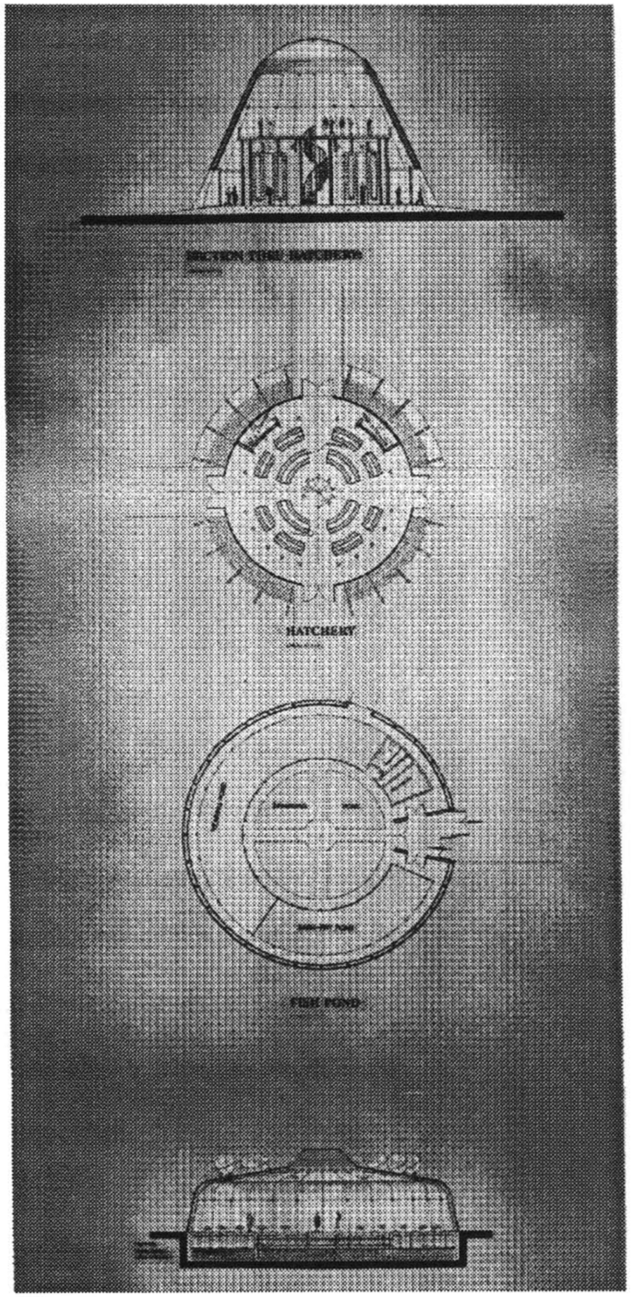


Figure 3L : Schematic Design of Aquaculture Facility

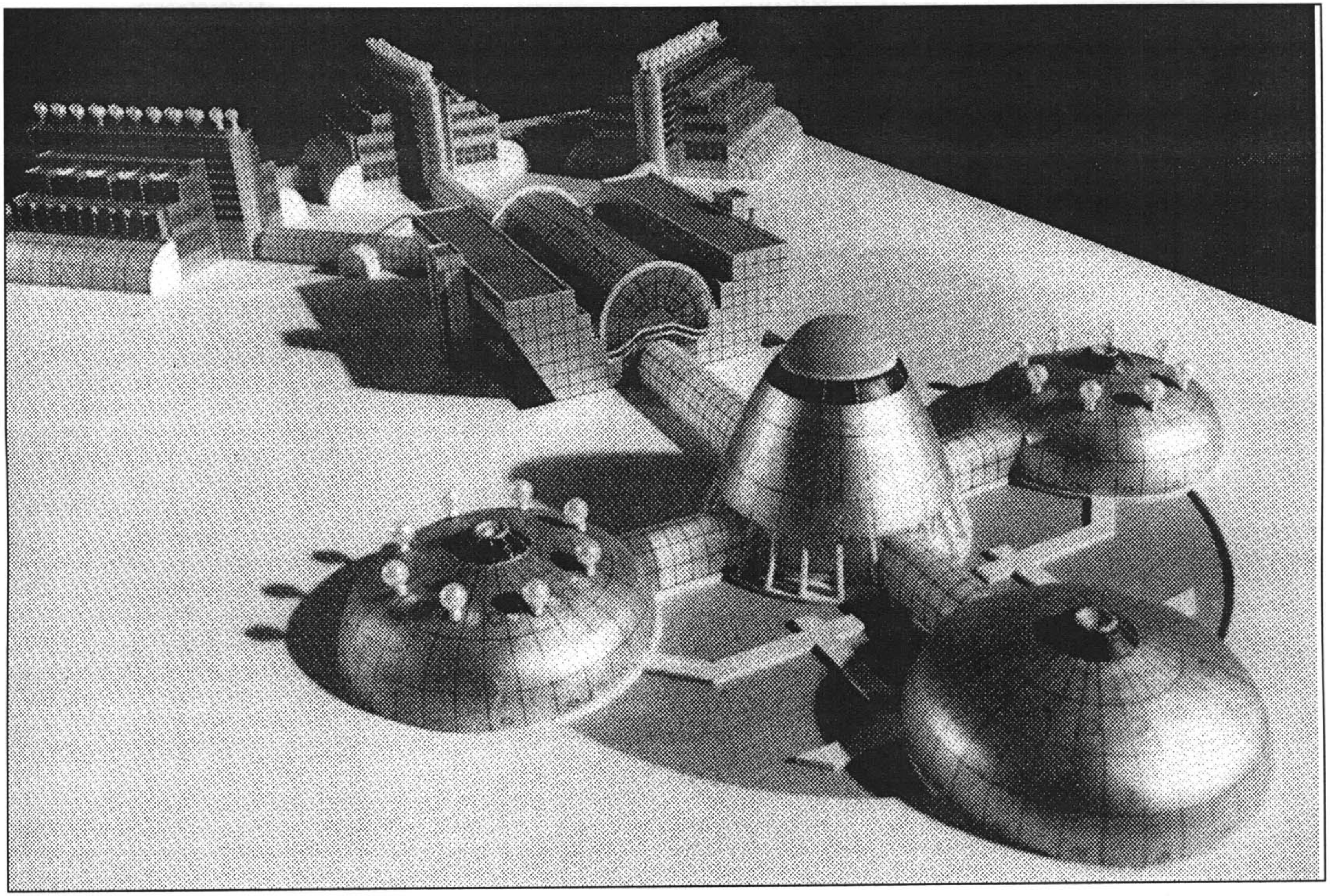


Figure 3m :Model of Conceptual Design

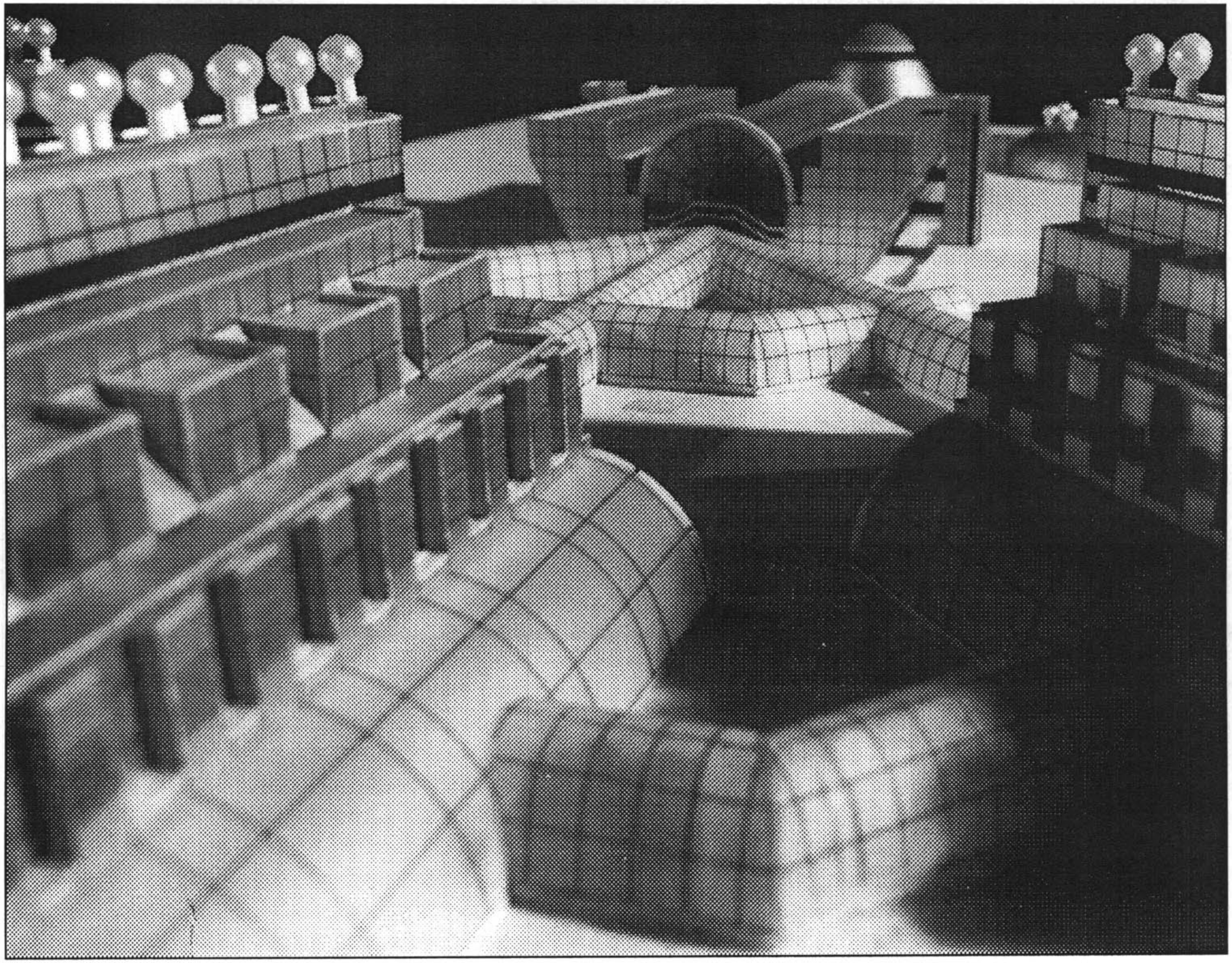


Figure 3n : Model of Conceptual Design

The conceptual and schematic design phases end with an architecture that truly reflects the functions within each component of the farming complex. An architecture that is futuristic in appearance, but very functional for the present (fig. 3m, 3n,). The conceptual and schematic designs present the foundation for a final and much more developed architectural solution. These designs sets the tone for the second part of this thesis presentation :
"Designing with Climate."

PART 2

"DESIGNING WITH CLIMATE"

AN OVERVIEW :

The second part of this thesis will present the design development phase of this proposed food production facility. The author will attempt to show how the conceptual designs have laid the foundation for the design development. This portion of the thesis will explore in great depth, the climatic conditions and weather variations throughout the year for the Caribbean and other Equatorial climates. The thesis will show how available sunlight in these climates can be integrated into the plant growth and aquaculture environments to supply photosynthetic active radiation. As discussed in Chapter 2, the term "light" and "photosynthetic active radiation" will be used interchaningly. However, the author acknowledges that most plant scientists state that " the word light is improper since light defines the electromagnetic radiation sensed by human vision.[12]

Also discussed here are techniques used to reduce thermal and solar loads that attempt to penetrate the buildings through the Lo _ E glazing used for top and side lighting. Alternative energy sources are also explored for driving the air-conditioners that are sometimes necessary to remove the solar gains. This section also shows how the prevailing winds could be used for cross-ventilation cooling whenever the outdoor climatic conditions are pleasant, or whenever there is an interruption of the generating power.

CHAPTER 4 :

DESIGNING FOR DAYLIGHT QUANTITY WITHIN THE PLANT GROWTH ENVIRONMENT

At the beginning of the design development it was decided that the Caribbean island of Trinidad which is located 10deg.N and 60deg.W, would be chosen as a case study. The climatic conditions of this island were much more thoroughly analyzed than that presented in the conceptual and schematic studies. First of all, Trinidad presents a very unique situation in which sunlight is available for an average of twelve hours per day, each month of the year — sunrise to sunset (Fig. 4a).

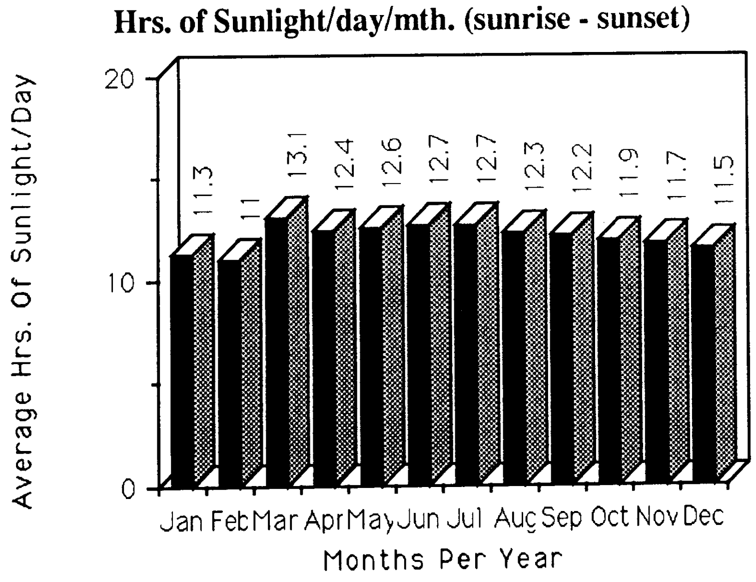


Figure 4a: Average Hrs. of Sunlight Per Day/Month

During this twelve hour period there is an average of eight hours of direct sunlight. However the intensity of the available sunlight varies in accordance with the climatic conditions of this island. Basically, there are two climatic divisions in Trinidad, as well as the rest of the Caribbean : "the sunny season and the rainy season." During the sunny/dry season, which spans from January to June, the average daily outdoor horizontal irradiance ranges from 891 f.c. (9623 lux) at 7:00am and 5:00pm in the month of January, to a high of 10,761 f.c. (116,219 lux) at 12:noon in the month of March. In contrast, the rainy/wet season which spans from July to December and gives off an average rainfall of 7.5 inches per month, has more overcast days than during the dry season. The average daily outdoor horizontal irradiance gets as low as 671 f.c. (7247 lux) at 7:00am and 5:00pm in the month of December (when there is the least amount of available sunlight), and as high as 8643 f.c. (93,247 lux) at 12:noon during the month of October (fig. 4b, 4c, 4d).

Figure 4b Average Irradiance @ 7:00am/5:00pm/M'th.

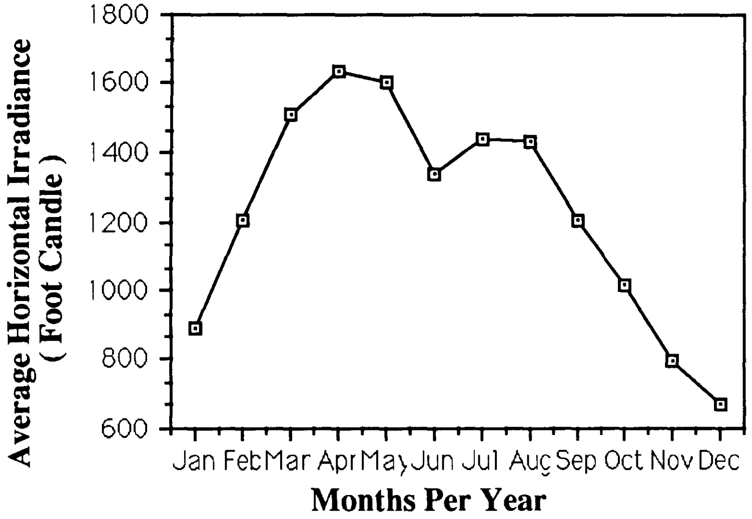


Figure 4c Average Irradiance @ 12:00 Noon/M'th.

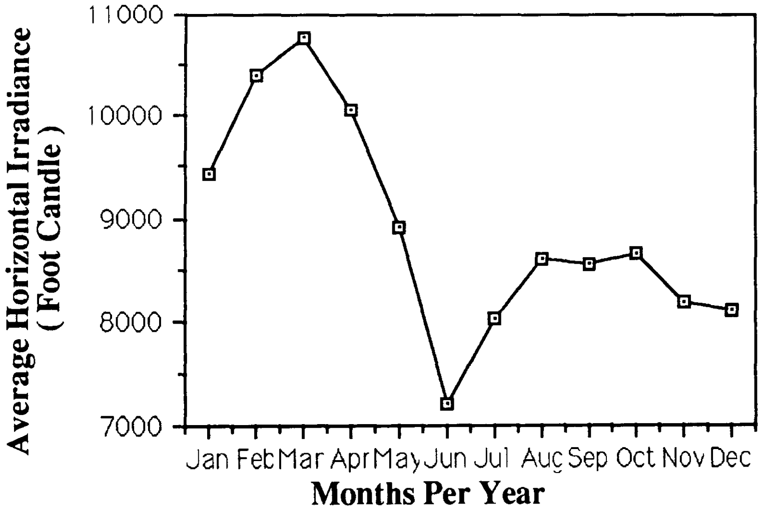


Figure 4d: Average Horizontal Irradiance/year

Jan. 21	Am	Pm	Av. Horizontal Irradiance (Foot Candle)
	7	5	891
	8	4	3495
	9	3	5962
	10	2	7846
	11	1	9046
	12	12	9423
Feb. 21	Am	Pm	
	7	5	1201
	8	4	4099
	9	3	6749
	10	2	8728
	11	1	9999
	12	12	10388
Mar. 21	Am	Pm	
	7	5	1507
	8	4	4520
	9	3	7138
	10	2	9183
	11	1	10402
	12	12	10761
Apr.21	Am	Pm	
	7	5	1636
	8	4	4385
	9	3	6786
	10	2	8631
	11	1	9709
	12	12	10057

cont'd ...

cont'd ...

May.21 Am	Pm	Foot Candle
7	5	1606
8	4	3983
9	3	5878
10	2	7388
11	1	8577
12	12	8898

Jun.21 Am	Pm	
7	5	1338
8	4	3239
9	3	4899
10	2	6157
11	1	6960
12	12	7201

Jul.21 Am	Pm	
7	5	1443
8	4	3592
9	3	5418
10	2	6861
11	1	7715
12	12	8009

Aug.21Am	Pm	
7	5	1434
8	4	3753
9	3	5798
10	2	7354
11	1	8300
12	12	8605

Sep.21 Am	Pm	Foot Candle
7	5	1207
8	4	3563
9	3	5683
10	2	7273
11	1	8245
12	12	8539

Oct.21 Am	Pm	
7	5	1019
8	4	3388
9	3	5576
10	2	7255
11	1	8305
12	12	8634

Nov.21Am	Pm	
7	5	779
8	4	3028
9	3	5187
10	2	6806
11	1	7825
12	12	8185

Dec.21 Am	Pm	
7	5	671
8	4	2869
9	3	5066
10	2	6683
11	1	7721
12	12	8087

The amount of solar energy that reaches the earth's surface is determined by the path of the sun. As is true in all climates, each day the sun rises in the east and sets in the west. However, in the Caribbean and other Equatorial climates, the course that the sun takes to reach from east to west varies at different times of the year. During the months of April, May, June, July, and August the sun travels along a northerly course. Through the months of January, February, March, September, October, November, and December the sun travels along a southerly path. The angle at which the sun's rays intersect the earth's surface also contributes to the amount of energy reaching the earth. For example : a sheet of glazing mounted parallel to the earth's surface and perpendicular to the sun's rays will receive more solar energy than a vertically mounted sheet of glazing. However, as the sun moves across its path and the it's rays begin to take the form of a more acute angle to the earth's surface, the horizontal glazing receives less energy while the vertical glazing receives more solar energy.

This solar energy that reaches the earth's surface is further influenced by the distance travelled through the atmosphere. Because of the very high altitude of the sun in the Caribbean and other Equatorial climates solar energy travels through the least amount of atmosphere during peak hours of the day. The result is maximum energy reaching the earth's surface. However, as sunset approaches the altitude of the sun decreases, the sun's travel through the atmosphere increases, and less solar energy reaches the earth' surface (fig. 4e).

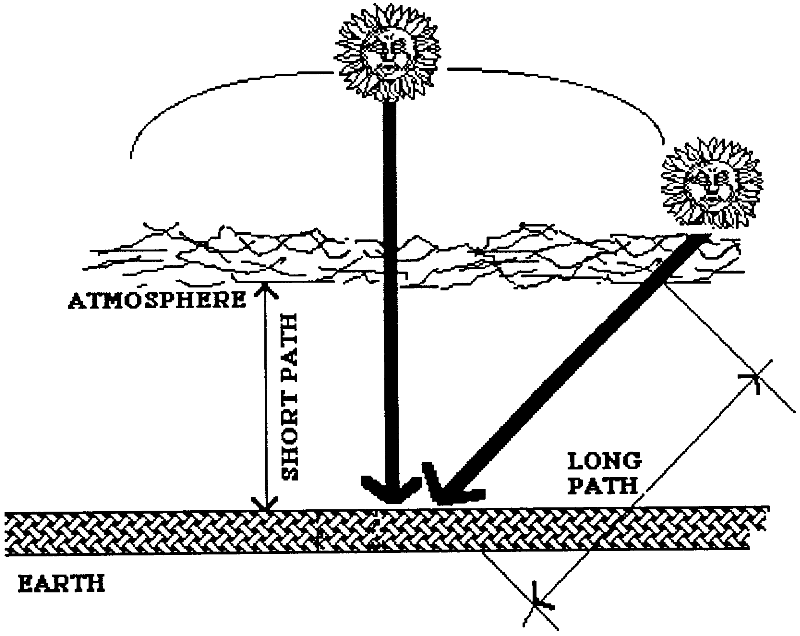


Figure 4e: The Sun's Path to the Earth's Surface

All of the above analysis has drastically influenced the orientation, and final design each of component of this proposed farming complex. It became very evident that the best technological and economic design solution was one in which the climatic conditions of Trinidad was integrated into the architectural design.

DESIGN SOLUTION :

The amount of light in the form of photosynthetic active radiation that reached the plants in the in the hydroponic facility depended on many important factors. The orientation of the building was the most important element to capture the most amount of daylight. While studying of the sun's path in the Caribbean it was discovered that much more solar energy penetrated vertical glazing on a east/west orientation than on a north/south orientation. Consequently, it was decided that all vertical glazing included in the design of the plant growth environment would be oriented towards the north and south. It was further decided that all walls oriented towards the east and west would be opaque.

Once the orientation of the plant growth environment was affirmed, the next step was to focus on techniques that will bring photosynthetic active radiation to the plants. But bringing light into a building cannot be separated from the heat content of the light. Consequently, an alternative other than ordinary clear glass, which has a very high solar energy transmittance, had to be used for the vertical glazing on the south and north walls of the proposed plant growth controlled environment. Lo Emissivity (Lo_E) glazing was the only type of glazing that presented the best balance between light transmittance and heat rejection.

In order to validate this conclusion, both ordinary clear and Lo_E clear 1/4" thick glass, were analysed for their shading coefficient, and daylight transmission properties. First of all, it was quite evident that ordinary clear 1/4" thick glass, which has a daylight transmission property of 86%, would transmitt more daylight than the proposed Lo_E clear, which is capable of transmitting 81% daylight. However, the ordinary clear glass has a shading coefficient of 1.00, compared to the proposed Lo_E glazing which has a 0.70 shading coefficient. Addationally, a heat gain transmission test was then conducted for the southern vertical glazing of the second floor of the plant growth facility. The size of the window was 20 ft high by 100 ft long. The test was done for the average worst time of the day for each month. For a typical year, the most heat gain through a vertical glazing happened at at 11:00 am. during the month of December. The test results showed a heat gain of 352,000 Btuh. (176Btuh/sq ft) through the ordinary clear glazing, and a heat gain of 246,400 Btuh. (123 Btuh/sq ft) through the Lo_E clear glazing. The Lo_E clear glazing which is being used to minimize the heat content of light that enters at the perimeter and top of the hydroponic structure was clearly the best choice of the two glazing for daylight transmission and heat rejection.

Since most vegetables need a minimum of 1200 f.c. (12960 lux), several daylight techniques were explored to transmitt daylight through the Lo_E glazing. All these daylight analyses were based on average cloudy days. Studies of perimeter lighting indicated that insufficient quantities of daylight was transmitted through the Lo-E glazing.

In addition, because of the very high altitude of the sun during the prime hours of the day in the Caribbean and other Equatorial climates, daylight was unable to penetrate beyond the perimeter of the plant growth facility (fig. 4f).

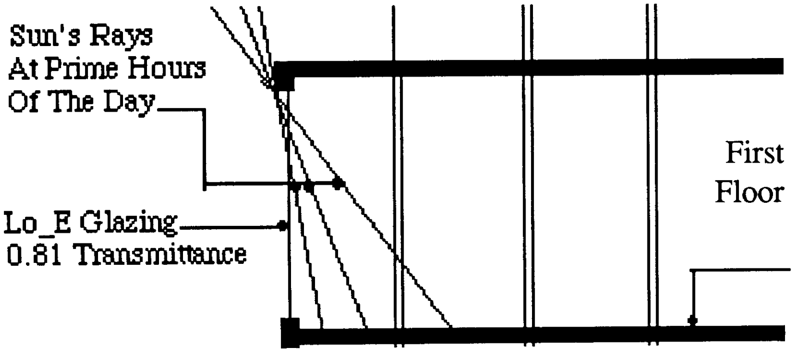


Figure 4f: Daylight Penitration at Perimeter of 1st. FL.

This development led to a combination of perimeter and reflective lighting techniques, which proved to be the exact chemistry for daylight transmission and penetration on the ground, first and second floors of the plant growth facility. Light shelf reflective lighting was also very instrumental in the lighting design of all floors.

In this strategy, light shelves paved with white quartz gravel reflects energy through the vertical Lo_E glazing, onto the interior ceiling and walls, which then reflects energy onto the mature plants within the hydroponic environment (fig. 4g).

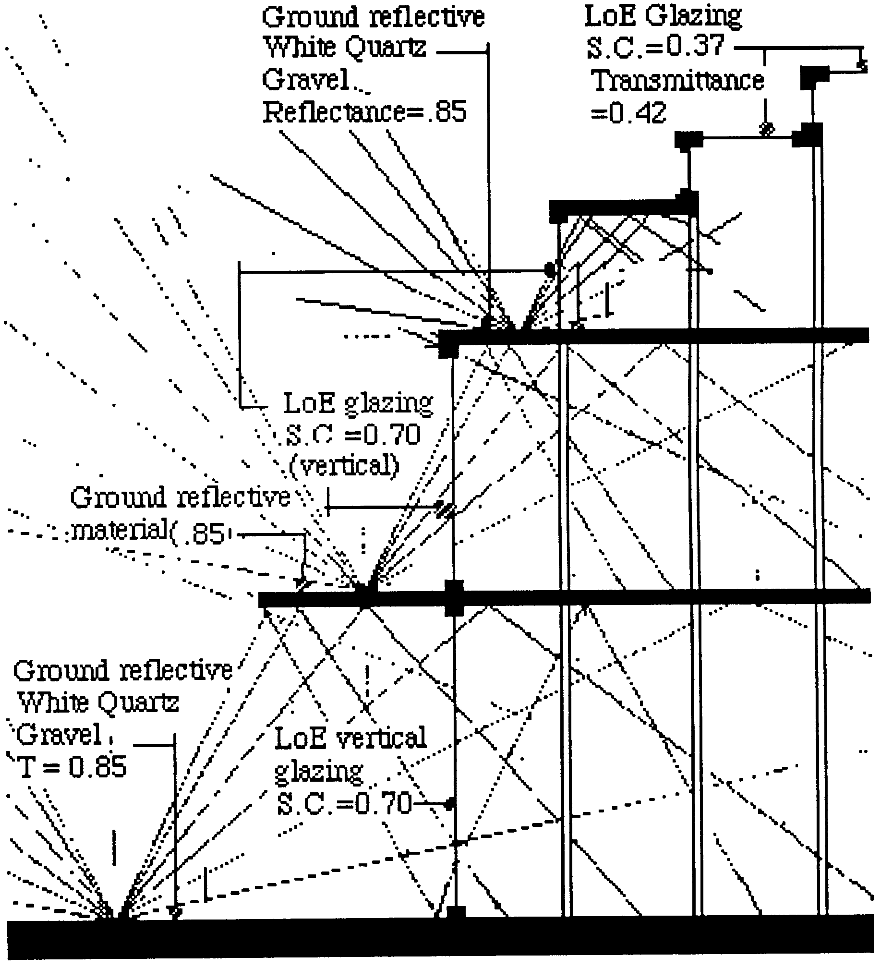


Figure 4g: Light Shelf and Perimeter Lighting

On the ground of this farming complex, white quartz paving is extended to the north and south sides of the hydroponic facility, one and a half (11/2) times the height of this building. This ground white quartz paving increases the energy reflectance into the plant growth environment. The white quartz gravel has a reflectance value of 85%, the high reflective ceiling has a reflectance value of 90%, and the clear Lo_E has a light transmittance value of 81%. The major advantage of using lightshelves is that, by reflecting light onto the ceiling of the plant growth facility and diffusing it, they allow daylight to penetrate farther into the interior of the building, therefore, extending the depth of the peripheral zone benefitted by the daylight.[16]

The second floor of the plant growth environment presented a very different lighting scenario. First of all, the second floor was the last floor of this facility. Secondly, this floor, totally devoted to plant growth, was exposed to the sky. The challenge was then to minimize heat gain through the skylights. This challenge of reducing heat gain through the glazing on the second floor was addressed by a series of designs that manipulated perimeter, reflective, and top lighting techniques. Figure 4i showhs one scheme that combined single glazing and double glazing Lo_E. The vertical Lo_E glazing has a daylight transmittance value of 81%, and a shading coefficient of 70%.

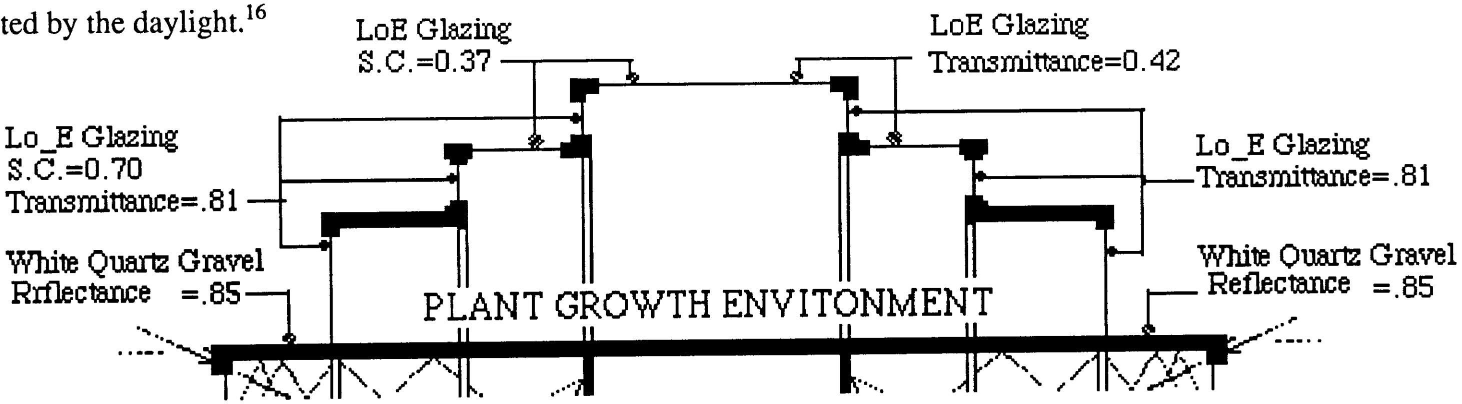


Figure 4i: Schematic Design for 2dn FL. of Plant Facility

The horizontal clear, double glazing, is coated with a Lo_E film that has a daylight transmittance value of 42%, and a shading coefficient of 37%.

Now, since during the rainy season less horizontal irradiance was available due to cloudy and overcast skies when compared with available sunlight during the sunny season, it was decided that the design development would present an architectural solution based on the diffused sunlight. This meant that the plant growth environment had to be designed to meet the required lighting quality and quantity for a worse condition. However, whether perimeter, reflective or top lighting is used to bring photosynthetic active radiation into the plant growth environment, cloud filtered daylight reaches the plants via the three routes shown in figure 4j.

Diffuse light from the sky vault reaches the plants via any line that does not intersect an obstruction (shown as, the Sky Component).

On cloudy days the sky component will be always greater than the external reflected component discussed below. Additional skylight is reflected to the plants from the ground and lightshelves (shown as, Direct Radiation (*External Reflected Component*). Both the ground and lightshelves have a 85 % reflectance value. Light from the first two sources reflects off the ceiling and walls to illuminate the plants indirectly (shown as, Internal Reflected Component).[17] In order to increase the internal reflectance component, the interior walls and ceiling were designed for a 90% reflectance value, the floor 50%, and the vertical glazing 15% reflectance.

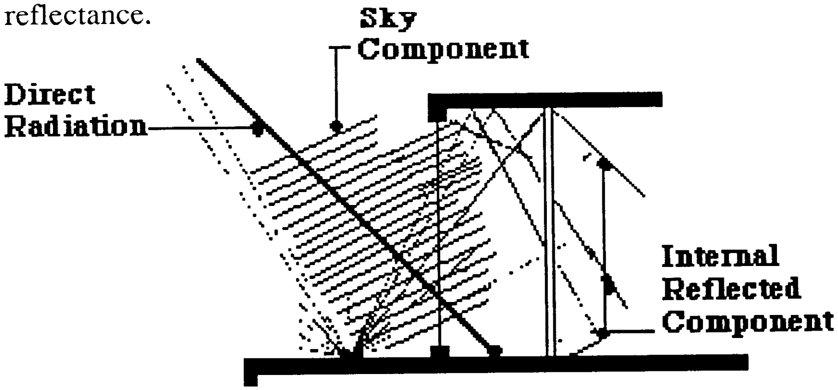


Figure 4j: Daylight Components

With the use of a protractor designed by the British Research Station it was possible to calculate the Sky Component for cloudy days (Fig. 4k).

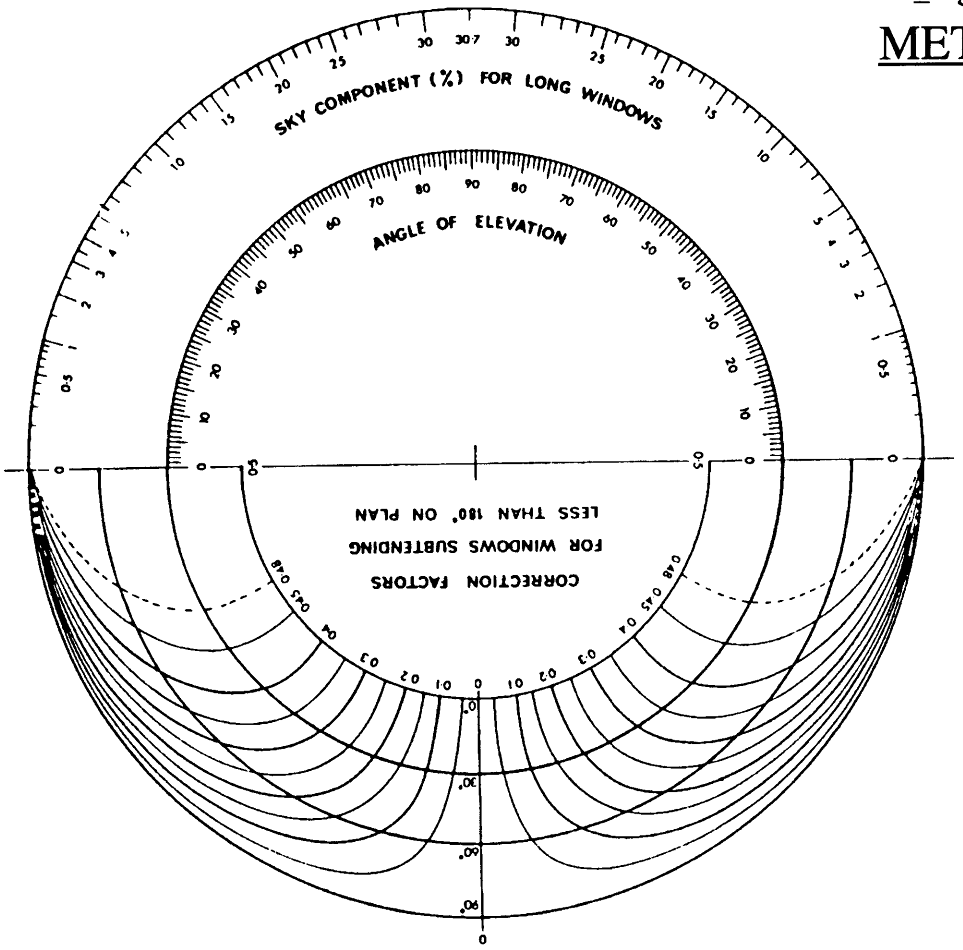


Figure 4k: BRS Sky Component Protractor

Once the I.R.C., S.C. and E.R.C. were totaled to find the final Daylight Factor, it was possible to calculate the exact lighting levels at five feet (5 ft) intervals from the vertical Lo_E glazing.

METHODS :Daylight Level Determination Methods

a. Using the section through the plant growth environment a point was selected on the first floor, 25 ft. from the vertical glazing where the seedlings enter the plant growrh environment (fig. 4L).

b. A line was drawn from that point on the ground to the highest limit of the window at which the sky was seen.

c. In order to read the value of the sky component where the upper and lower limit lines intercepted the protractor's edge, the center of the BRS protractor was superimposed on the point 25 ft. from the window and flush with the ground of the second floor.

d. The resulting sky component was 6.0 for an infinitely long window (fig. 4L).

e. While this portion of the protractor was still superimposed, the mean altitude of the visible sky was noted from the inner scale (37 deg.).

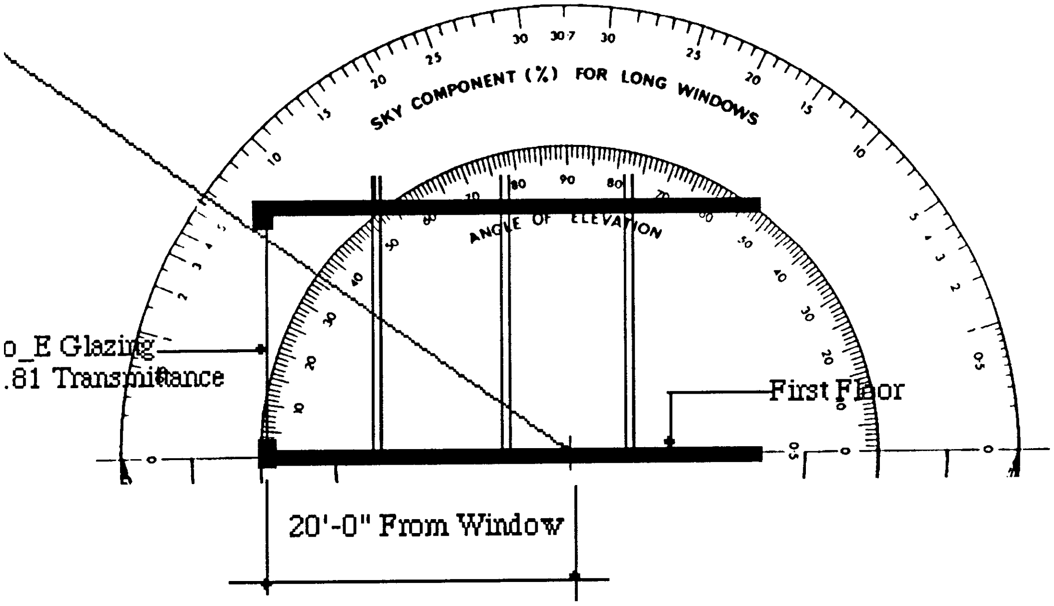
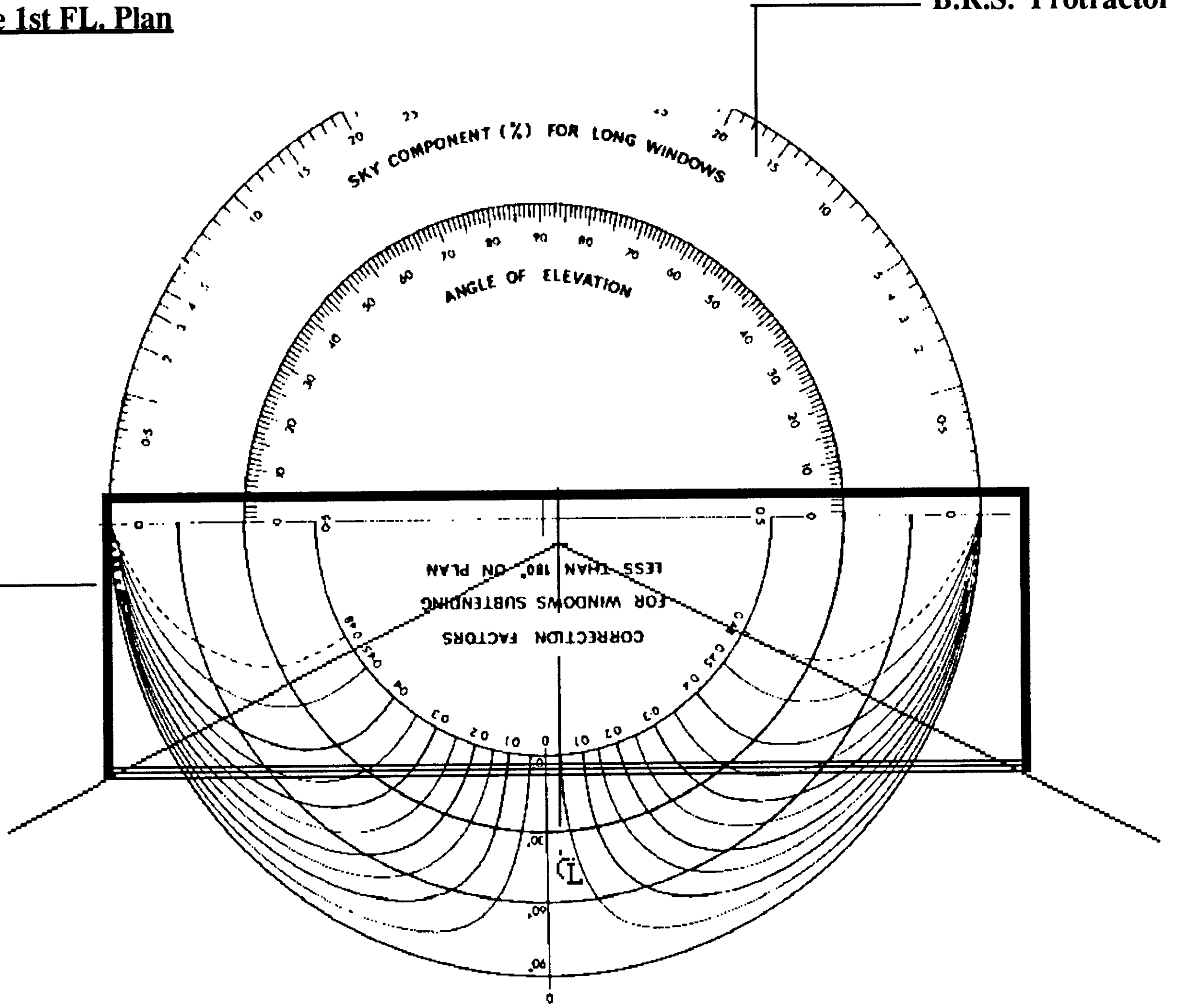


Figure 4L: BRS Protractor & Partial Section thru. 1st FL

f. A correction for the actual length of the vertical glazing was found by using the first floor plan with the other half of the BRS protractor :

1. Using the first floor plan, lines were drawn from the two edges of the window (the visible sky) to the point 25 ft. away.
2. The center of the correction factor side of the protractor was then placed over the point, with its base parallel to the window.
3. Using the mean altitude of the visible light found above, the correction factor for each edge of the window where the limit lines intersected the protractor was found to have a value of 0.48 and 0.48. The addition of these two values gave the total correction factor (fig. 4m).

Figure 4m: An Example of the use of the BRS Protractor Superimposed on the 1st FL. Plan



4. The Corrected Sky Component for the true length of the vertical glazing was found when the sky component found above was multiplied by the total correction factor, = 5.76.

g. The External Reflected Component was 10% the corrected sky component, = 0.576 (Due to the outdoor reflective white quartz gravel, this figure will be higher. The following step supports this premise.)

The next very important element for calculating the daylight factor is the average Internal Reflected Component (IRC). The following proceidure was used to calculate the average (IRC) for the point 25 ft from the vertical glazing.

h.

FIRST FLOOR

CEILING:

90% OF 3000 SQ. FT. = 2700 SQ. FT.

(90%, 50%, 15%=average reflectance of ceiling/wall, floor and glass)

FLOOR :

50% OF 3000 SQ. FT. = 1500 SQ. FT.

VERTICAL WALLS:

90% OF 3200 SQ. FT. = 2880 SQ. FT.

GLASS WALL :

15% OF 2000 SQ. FT.= 300 SQ. FT.

TOTAL Surface AREA = A(ceiling)+A(fls.)+
A(walls)+A(win'w)

3000++3000+3200 SQ. FT.+2000SQ. FT.

= 11,200 SQ. FT.

$$\text{Average Reflectance Factor} = \frac{7{,}380 \text{ SQ. FT.}}{11{,}200 \text{ SQ. FT.}}$$

(where 7380 sq ft = 2700+1500+2880+300)

= .66 OR 66%

$$\text{Area of glass wall / Total Surface Area} = \frac{2000 \text{ SQ. FT.}}{11{,}200 \text{ SQ. FT.}}$$

= 0.18

From the nomograph in figure 4n, the Average Internal ReflectedComponent =11.5%

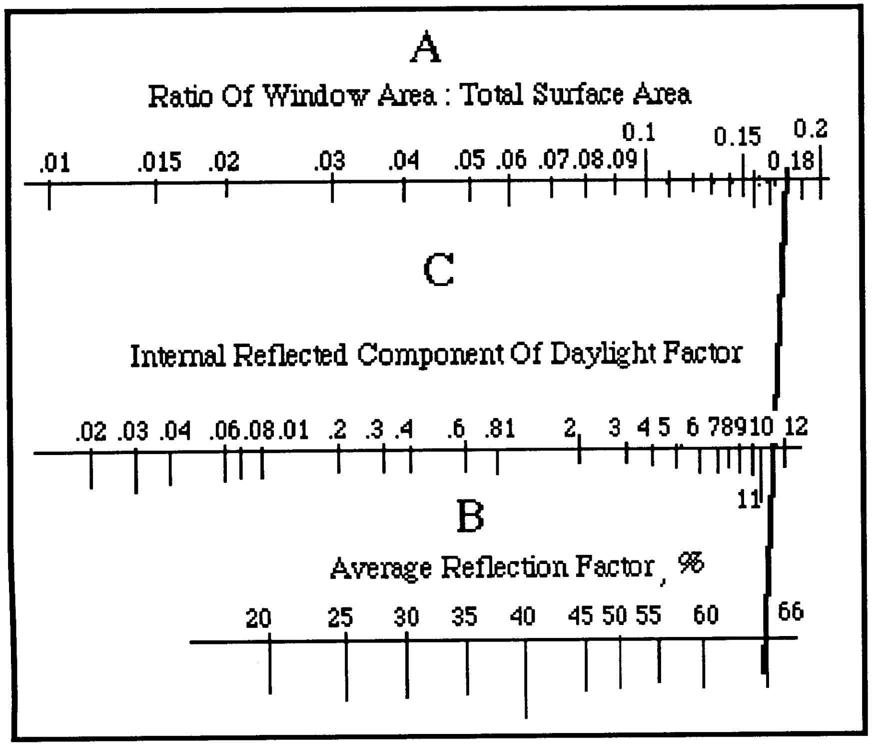


Figure 4n: Nomograph

DAYLIGHT FACTOR = 5.76+0.576+11.6

= 17.8%

Now, there has to be an added correction to the daylight factor, to account for the increased ground reflectance off the white quartz gravel.

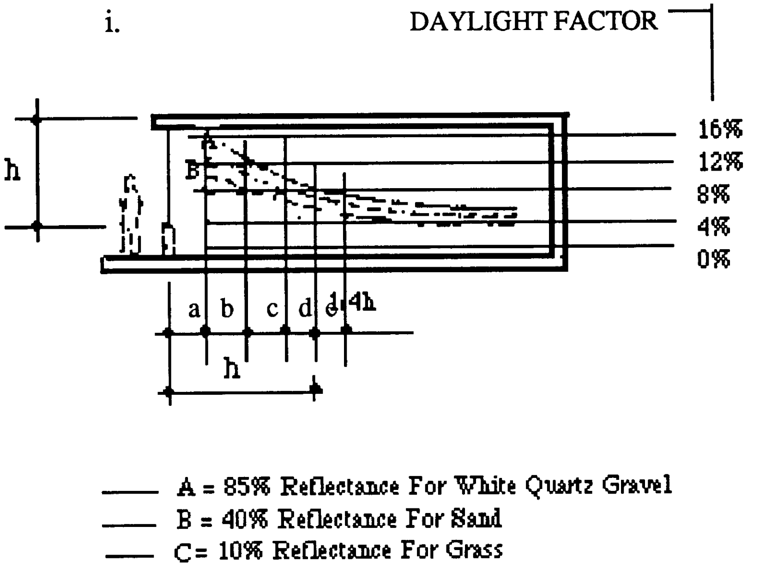


Figure 4o: The effect of Outside Reflective Surfaces on Internal Natural Daylight

The diagram above is for a space with white walls, similar to the plant growth environment. Basically the figure is a graph in terms of distance versus daylight factor for white quartz gravel, sand and grass.

From the graph **h = 20 ft.** = the height of the vertical window on the first floor. The respective distances from the window are as follows : "a" = 5 ft, "b" = 10 ft., "c" = 15 ft., "d" =20 ft., "e" = 25 ft.

From the graph, the matching daylight factors for white quartz gravel and grass are : DFwqg = 8, DFgrass= 5

This implies that DFwqg/Dfgrass = 8/5 = 1.6

So, DF (final) 25 ft. from window = DF*DFwqg/DFgrass

= 17.8*1.6

= 28.48%

k. Now the available daylight 25 ft from the window was then calculated by multiplying the outdoor horizontal irradianceby the daylight factor. This product was then further multiplied by the Lo_E transmittance factor of 0.81 to find the exact photosynthetic active radiation available to the crops, 25 ft from the window, within the plant growth environment (fig. 4p).

Figure 4p

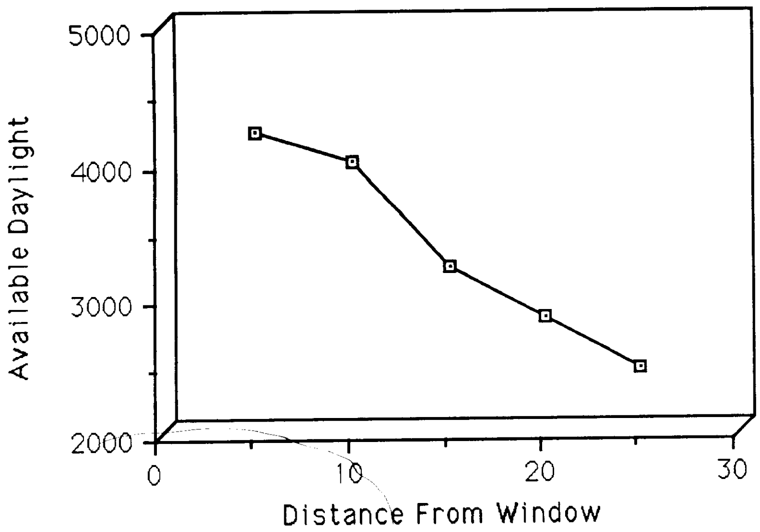
	Am	Pm	Hor Irradiance (Foot Candle)	DF (final)= 0.2848	T= 0.81
Jan.					
	7	5	891 FC	254 FC	206 FC
	8	4	3,495	995	806
	9	3	5,962	1,698	1,375
	10	2	7,846	2,235	1,810
	11	1	9,046	2,576	2,087
	12	12	9,423	2,684	2,174
Feb.					
	7	5	1,201	342	277
	8	4	4,099	1,167	945
	9	3	6,749	1,922	1,557
	10	2	8,728	2,486	2,014
	11	1	9,999	2,848	2,307
	12	12	10,388	2,959	2,397
Mar.					
	7	5	1,507	429	347
	8	4	4,520	1,287	1,042
	9	3	7,138	2,033	1,647
	10	2	9,183	2,615	2,118
	11	1	10,402	2,962	2,399
	12	12	10,761	3,065	2,483
Apr.					
	7	5	1,636	466	377
	8	4	4,385	1,249	1,012
	9	3	6,786	1,933	1,566
	10	2	8,631	2,458	1,991
	11	1	9,709	2,765	2,240
	12	12	10,057	2,864	2,320

	Am	Pm	Foot Candle	Foot Candle	F. C.
May.					
	7	5	1,606	457	370
	8	4	3,983	1,134	919
	9	3	5,878	1,674	1,356
	10	2	7,388	2,104	1,704
	11	1	8,577	2,443	1,979
	12	12	8,898	2,534	2,053
Jun.					
	7	5	1,338	381	309
	8	4	3,239	922	747
	9	3	4,899	1,395	1,130
	10	2	6,157	1,754	1,421
	11	1	6,960	1,982	1,605
	12	12	7,201	2,051	1,661
Jul.					
	7	5	1,443	411	333
	8	4	3,592	1,023	829
	9	3	5,418	1,543	1,250
	10	2	6,861	1,954	1,583
	11	1	7,715	2,197	1,780
	12	12	8,009	2,281	1,848
Aug.					
	7	5	1,434	408	330
	8	4	3,753	1,069	866
	9	3	5,798	1,651	1,337
	10	2	7,354	2,094	1,696
	11	1	8,300	2,364	1,915
	12	12	8,605	2,451	1,985

	Am	Pm	Foot Candle	Foot Candle	F. C.
Sep.					
	7	5	1,207	344	279
	8	4	3,563	1,015	822
	9	3	5,683	1,619	1,311
	10	2	7,273	2,071	1,678
	11	1	8,245	2,348	1,902
	12	12	8,539	2,432	1,970
Oct.					
	7	5	1,019	290	235
	8	4	3,388	965	782
	9	3	5,576	1,588	1,286
	10	2	7,255	2,066	1,673
	11	1	8,305	2,365	1,916
	12	12	8,634	2,459	1,992
Nov.					
	7	5	779	222	180
	8	4	3,028	862	698
	9	3	5,187	1,477	1,196
	10	2	6,806	1,938	1,570
	11	1	7,825	2,229	1,805
	12	12	8,185	2,331	1,888
Dec.					
	7	5	671	191	155
	8	4	2,869	817	662
	9	3	5,066	1,443	1,169
	10	2	6683	1903	1541
	11	1	7,721	2,199	1,781
	12	12	8,087	2,303	1,865

The above method was used to calculate the available daylight at five feet intivals for the ground through second floors. An example of the daylight distribution 25 ft from the window, at 5 ft intivals, on the first floor, is shown in figure 4q. This graph represents the daylight distribution through the Lo_E glazing for the month of March, at 12:00 noon.

Figure 4q: **Available Daylight Vs. Distance Fm. Window**



CONCLUSIONS

The first presime established was the fact that most vegetables will grow well if they receive not less that 1200 fc of light within an approximate wavelength of 400 to 700 nm. Secondly, because of the amount of available sunlight on an average and sunny day on the island of Trinidad, very little artifical lighting was necessary to supply photosynthetic active radiation to the crops. Figure 4d indicated that on a typical day, at 12:00 noon, the average available horizontal irradiance is approximately 8,900 fc (96,120 lux). However, on a bright sunny day, the available sunlight far exceeds 10,000 fc (108,000 lux). As a result, extensive studies were done on bouncing daylight off reflective surfaces. On an average day all crops in the plant growth environment will receive photosynthetic active radation from the natural environment.

In the studies, white quartz gravel (85% reflectance) was used as a reflective surface to bounce sunlight through clear Lo_E glazing -- which was recomended to minimize the heat content of all entering light -- onto high reflective interior walls and ceilings (90% reflectance). From these points, the crops receive the diffused lighting required for optimum growth.

On the second floor, Lo_E clear single glazing with a light transmittance value of 81%, for vertical walls, and a clear Lo_E clear double coated glazing with a transmittance of 42%, for horizontal skylights, were both applied to the design of the second floor (see fig 4r & 4u). The result was an environment with annual daylight levels that range from 690 fc (7452 lux) to 4520 fc (48,816 lux) and optimum for the growth of crops such as tomatos (see appendix 1).

On the first and ground floors the lighting design was quite different to that of the second floor (see fig. 4s, 4t, & 4u). On the first two floors the lighting drops as one moves away from the vertical window. This observation was a result of measurements taken with a cosine corrected light meter om physical study models, and verified by mathemitical computations using the British Research Station Method. However, the lighting design on the ground and first floors presented two rather interesting situations :

1. On either floors, the point furthest away from the window would be the area where the young crops enter the plant growth facility -- directly from the seedling room. This is thepoint at which the daylight levels are weakest. As these crops grow stronger, and their need for greater lighting levels increases, the plants will be moved along the growth benches, towards the vertical glazing.

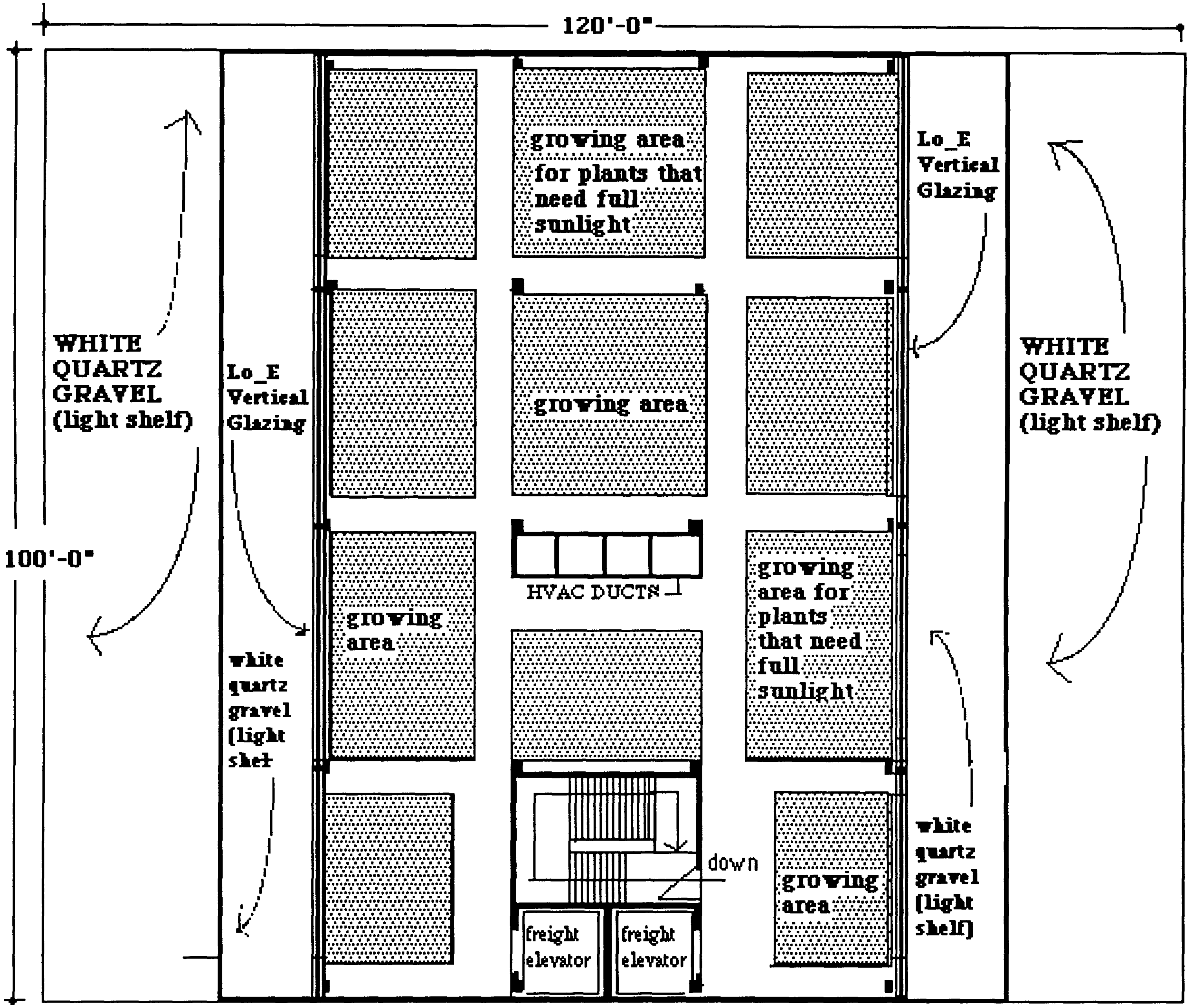


Figure 4r: Second FL. Plan of Plant Growth Environment; Scale=1/16'=1'-0"

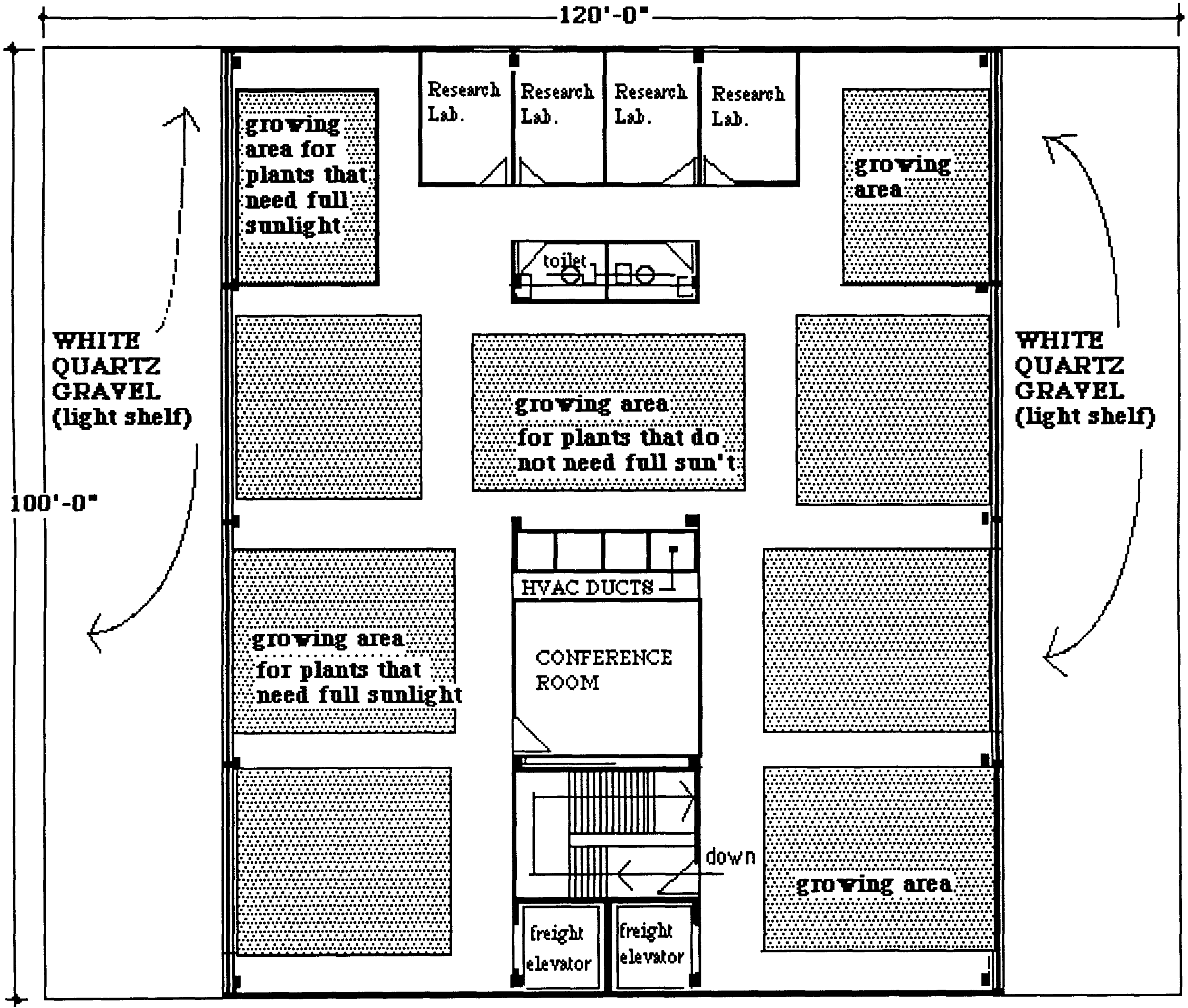


Figure 4s: First FL. Plan of Plant Growth Environment; Scale=1/16'=1'-0"

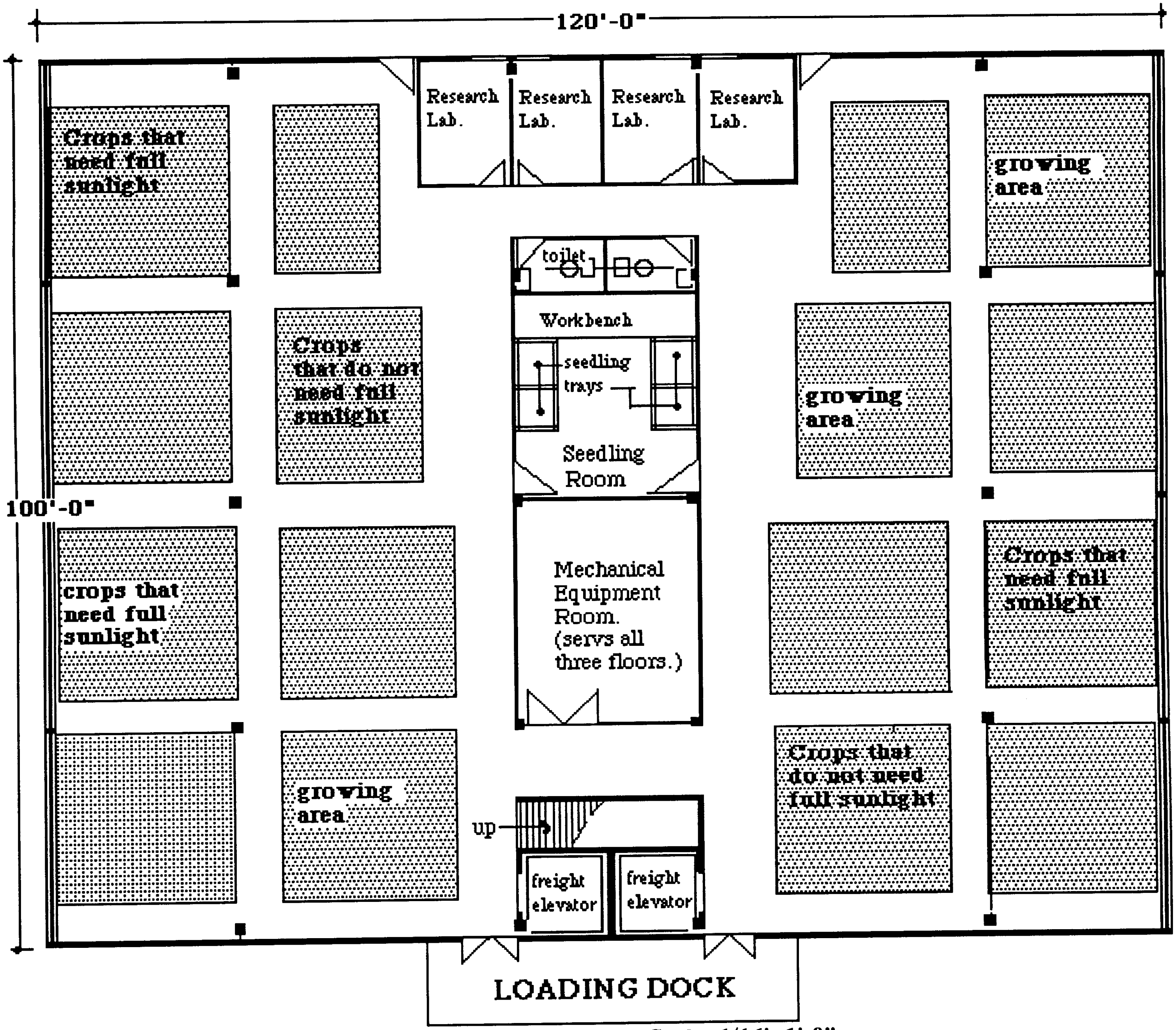


Figure 4t: Ground FL. Plan of Plant Growth Environment: Scale=1/16'=1'-0"

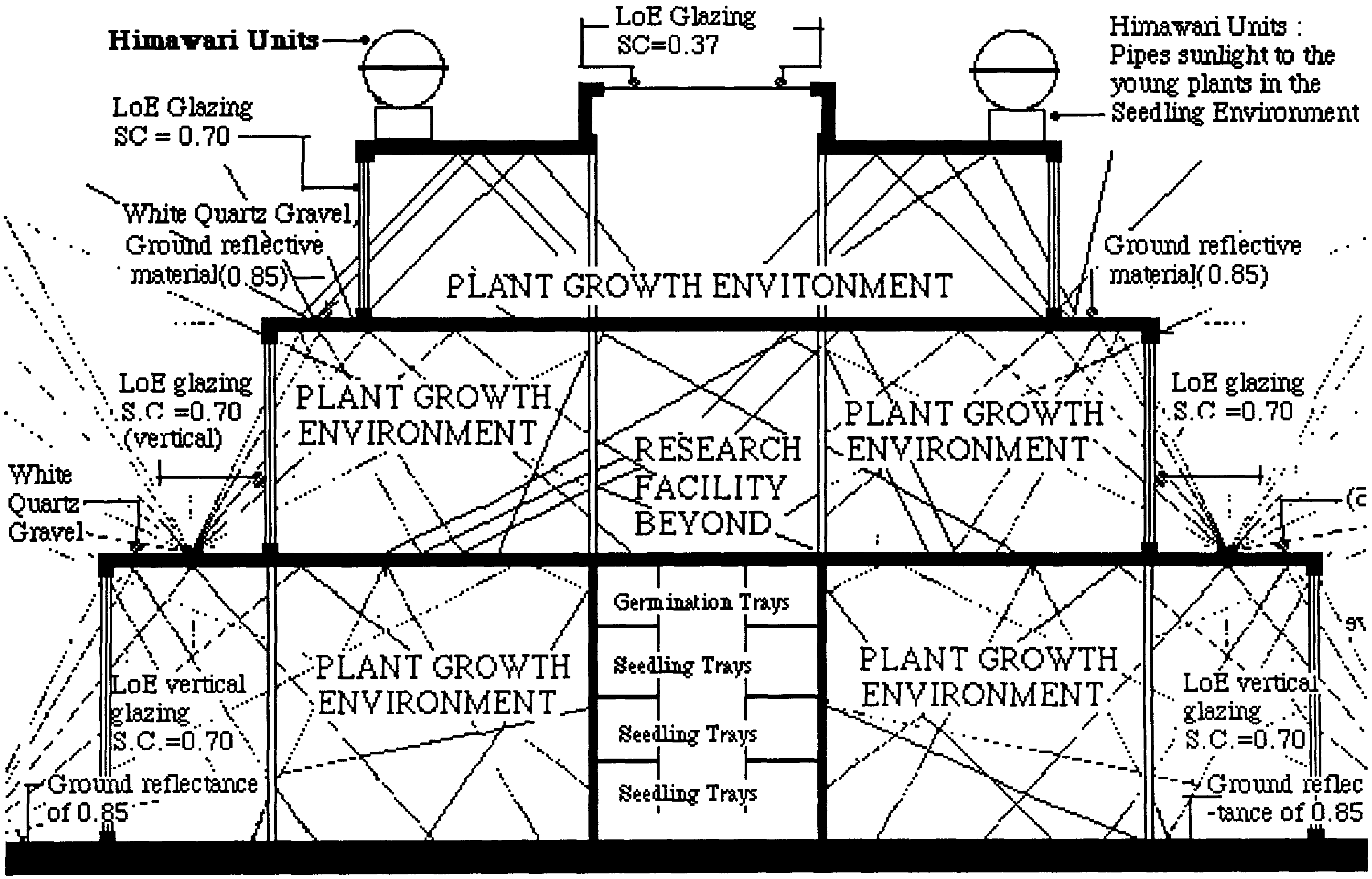


Figure 4u: Section Through Plant Growth Environment

2. Not all crops need full sunlight for optimum growth. Consequently, plants that need full sunlight will be grown on the perimeter of the ground and first floor, where the daylight levels are strongest. Crops like lettuce that do not need full sunlight for optimum growth will be grown further away from the vertical glazing. On the ground floor daylight levels range from 433 fc (4,676 lux) 45 ft from the window, to 4,341 fc (46,883 lux) 5 ft from the window. On the first floor the lighting quantity range from 662 fc (7,150 lux) 25 ft from the window, to 3,969 fc (42,865 lux) 25 ft from the vertical glazing (see appendix 1).

Based on the above analysis, it was discovered that there were very low levels of lighting within the crop facility at 7:00am and 5:00pm respectively. The initial thought was that this was due to the acute angle of the sun's elevation at those times of the day. Another theory was that low lighting levels occured at those times of the day because during different months of a typical year, the elevation of the sun is much lower when compared to other months. In order to test these theories and assumptions numerous sun studies were conducted on the entire farming complex. These sun studies were done with the use of a *sundial* for the latitude and longitude of Trinidad (fig. 4v). The sundial was placed on the northern portion of the model and tilted towards the light source so the shadow of the gnomon can intersect with the correct time of the day, and for the specified month. The findings for 7:00am are as follows:

a. During the months of January, November, and December, the plant growth facility located on the eastern section of site casted shadows, completely shading the ground floor of the plant growth environment located on the northern portion of the site (fig. 4w).

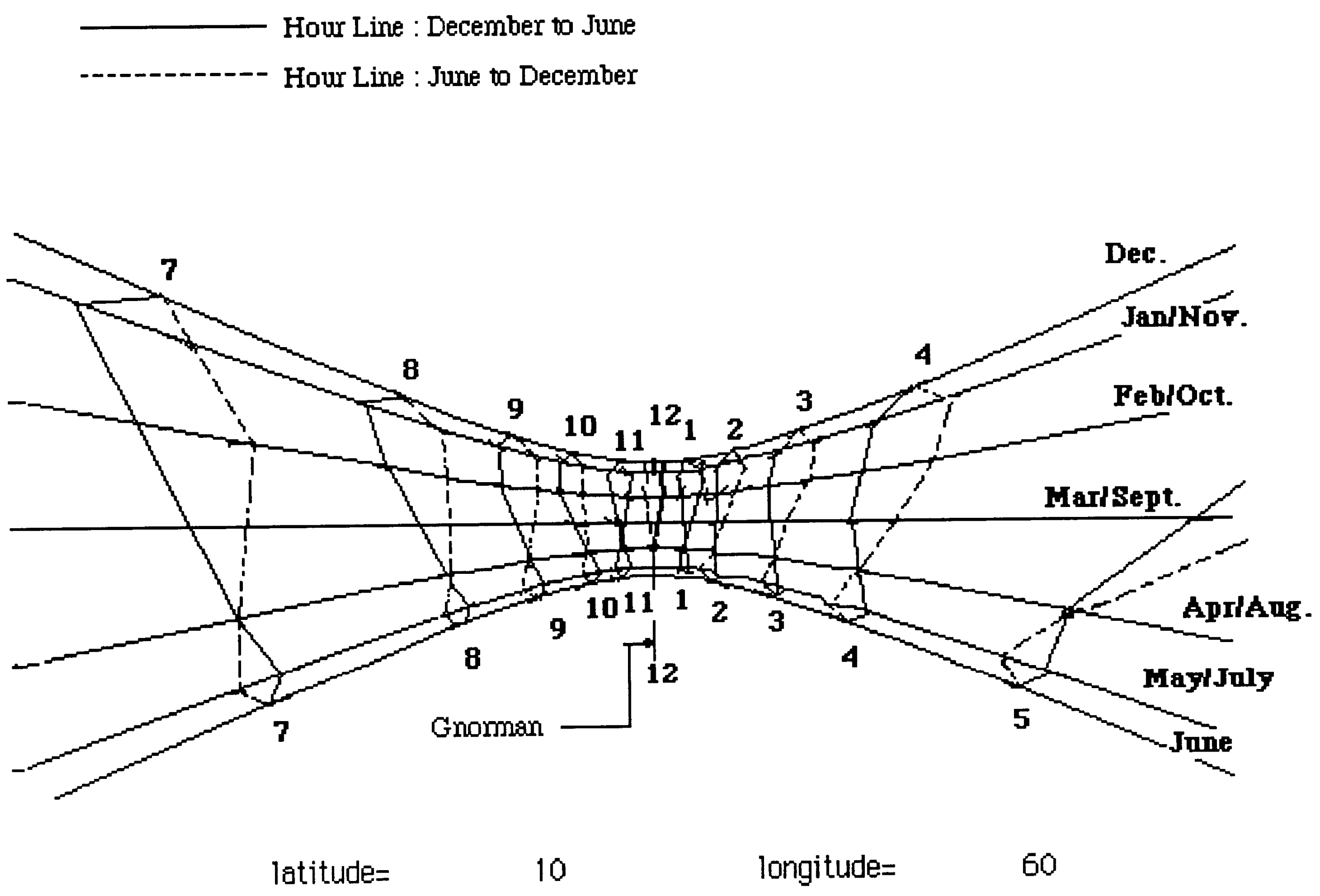


Figure 4v: Sundial for Trinidad' Latitude of 10^0 N. Longitude of 60^0 W

During these same months the plant growth facility located on the southern section of the site casted shadows on the southern-most controlled environment fish pond, totally shading the Himawari units mounted on the roof of the fish pond.

b. During the months of May, June, and July, the plant growth facility located on the eastern section of the site casted shadows, completely shading the ground floor of the plant growth environment located on the southern section of site. During these same months the plant growth facility located on the northern section of the site casted shadows on the northern-most controlled environment fish pond, totally shading the Himawari units mounted on the roof of the fish pond (fig. 4x).

The findings for 5:00pm are as follows :

a. During the months of May, June, and July, the plant growth facility located on the northern section of site casted shadows, completely shading the ground floor of the plant growth environment located on the eastern section of site (fig. 4y) .

These findings have confirmed the need to use supplimental artificial lighting to make sure that the plants receive the correct levels of lighting at all times. Crops in this facility will receive twelve hours of light and twelve hours of darkness during an average day (from 7:00am to 7:00pm). From 8:00am to 4:00pm, eight hours of daylight will be available to the crops on an average day. From 7:00am to 8:00am, and, 4:00pm to 7:00pm, whatever available sunlight will be supplemented with energy efficient artificial lighting. Anytime the daylight levels drop below 1200 fc (12,960 lux), the artificial lighting will be automatically activated.

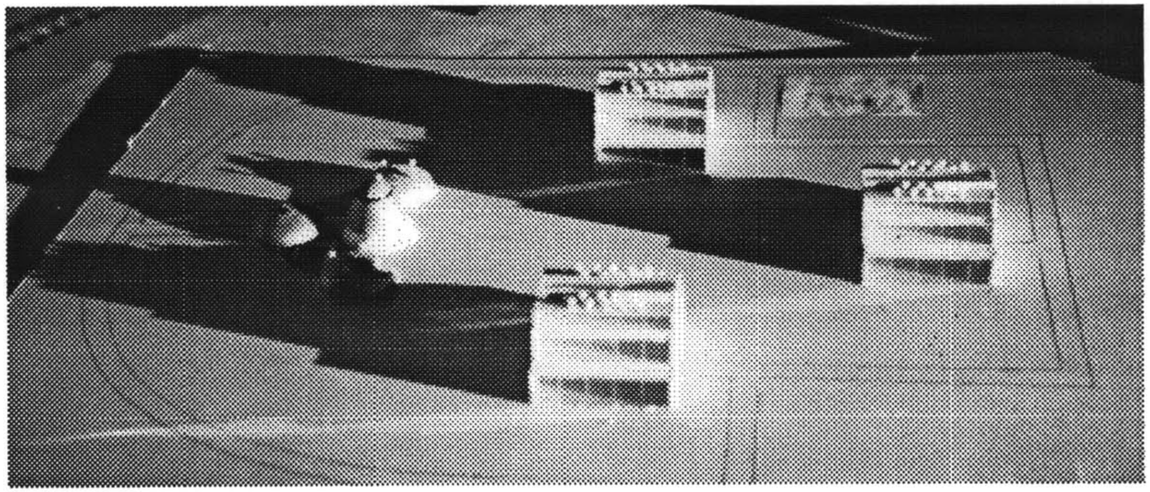


Figure 4w: Example of Sundial Study: Dec., Jan., Nov.7:00am

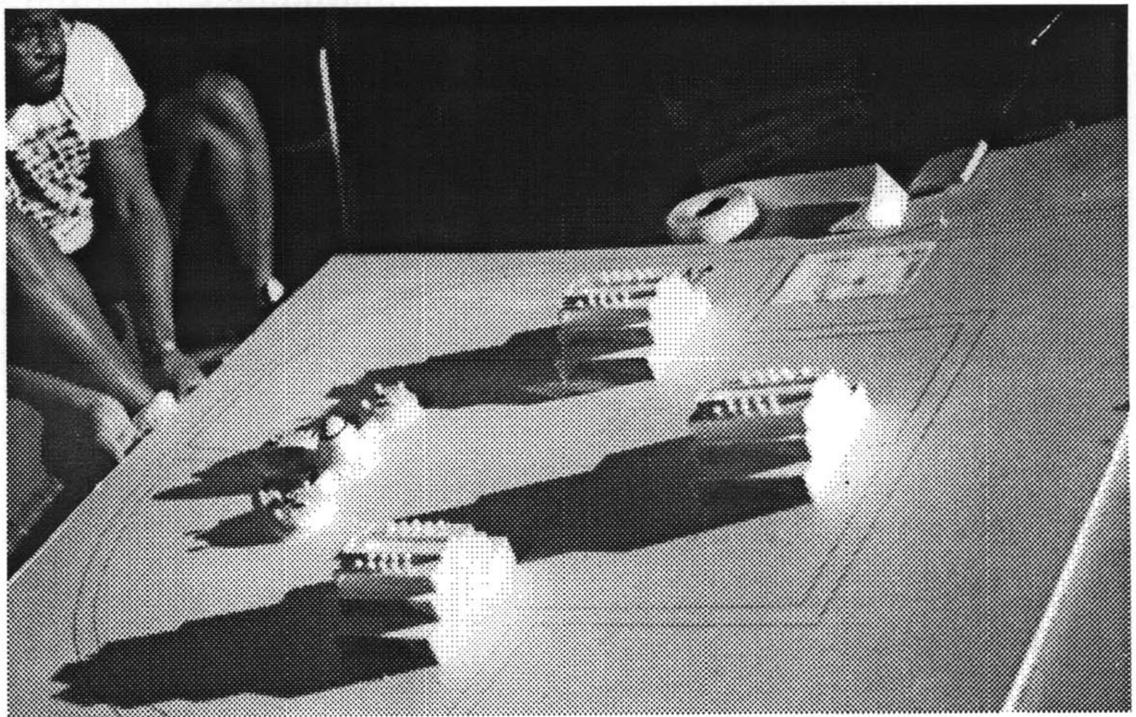


Figure 4x: Example of Sundial Study: May, Jun , Jul.7:00am

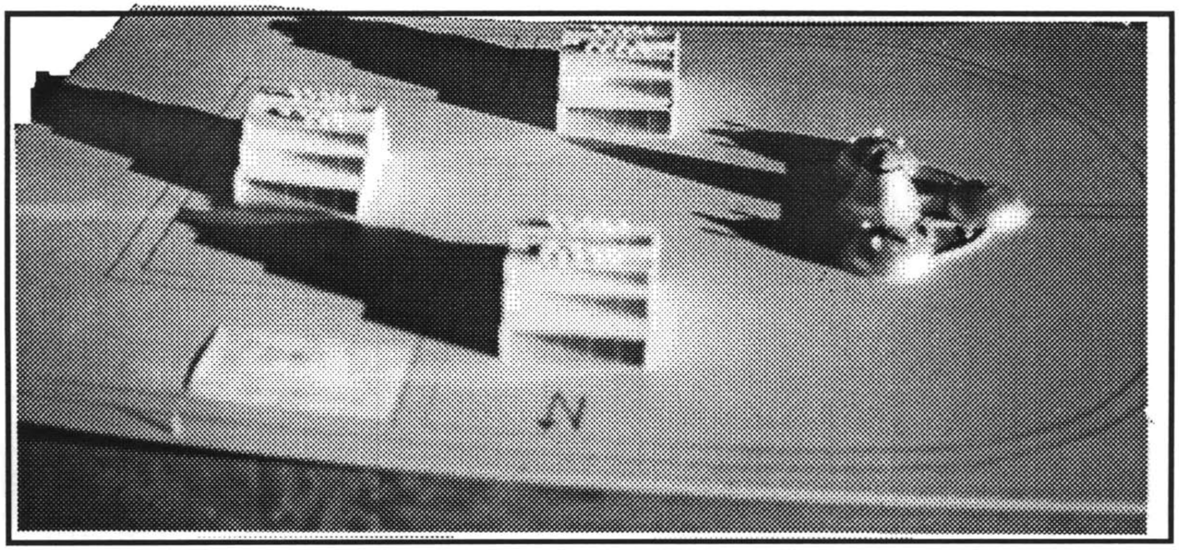


Figure 4y: Example of Sundial Study: May, Jun , Jul.5:00pm

Furthermore, during the rainy/wet season when some days are overcast, the artifical lighting will be extended through the night to compensate for inadequate daylight levels. Hence, during an average overcast day the plants will receive an extended four hours of artifical lighting. This results into sixteen hours of light and eight hours of darkness for the crops on overcast days.

A complete set of data for daylight penetration into the plant growth environment, for each floor, is illusrtated in Appendix 1.

CHAPTER 5 :

DESIGNING FOR DAYLIGHT QUALITY WITHIN THE PLANT GROWTH ENVIRONMENT

Daylight quality can be characterized as the combination of wavelengths radiating from the sun's energy. The portion of this radiant energy spectrum used by photosynthesis is called photosynthetic active radiation (PAR) which falls within the light spectrum of 400 - 700 nm.. Within this energy spectrum wavelengths of 400 - 500 nm provide blue energy, while those in the 600 - 700 nm range emit red energy. In addition, wavelengths in the 700 - 800 nm region provide far-red energy. Research into plant physiology has indicated that a proper balance of blue and red spectral energies will assure proper plants' growth response.

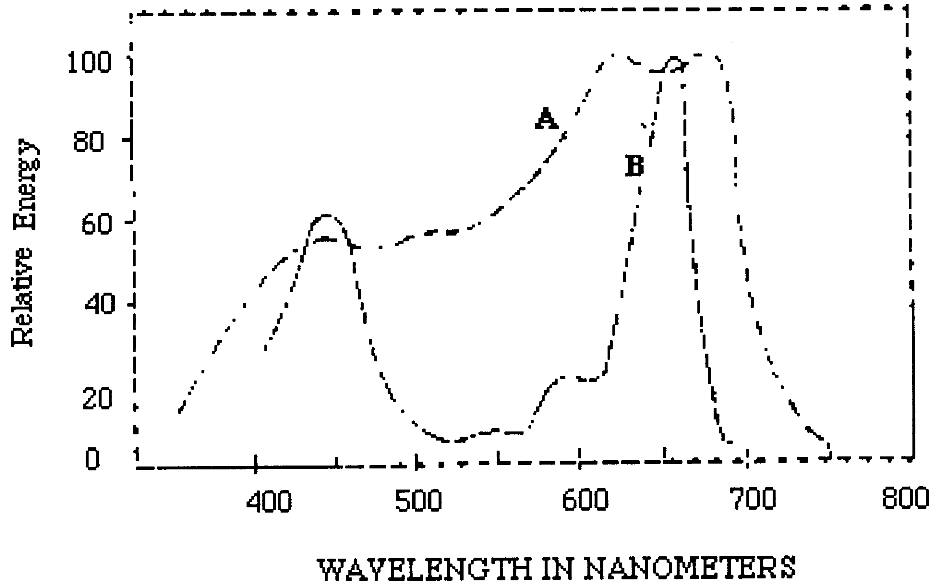
Light influences many phases of a plant's life. However, photosynthesis, chlorophyll synthesis, photoperiodism, and phototropism are much more influenced by the presence of light. Websters' dictionary has defined photosynthesis as "the formation of carbohydrates in the chlorophyll-containing tissues of plants that are exposed to light." During the day when the sun is out, respiration occurs along with photosynthesis. At night, or during the dark period, the respiration process continues and photosynthesis stops. For most plants, photosynthetic response peaks in the red band at 675 nm., and in the blue band at 435 nm. (fig. 5a). The rate of photosynthesis is quite often proportional to the intensity of light up to approximately 13,000 lux.

However, because of the shading effect, a maximum amount of light intensity is needed to provide all of a plant's leaves with optimum quantities of energy. On the other hand, not all plants respond to high light intensities. These shade plants may require as little as one-tenth of full sunlight.[18]

Chlorophyll, an organic compound of carbon, hydrogen, oxygen, and magnesium, is the green coloring matter of plants, and one of the chief agents in the process of photosynthesis.[19]

Whenever daylight or its equilivent is present, plant cells will produce chlorophyll. When light is absent, plants become pale and discolored, and will eventually die. Chlorophyll synthesis occurs in the violet and blue wavelengths (400 to 510 nm.) and in the red wavelength (610 to 700 nm.).

Figure 5a Action Spectrum of : (A) Photosynthetic Response (B) Chlorophyll Synthesis



Phototropism is the growth of plants towards or away from a light source. This plant reaction is quite active between the wavelengths of 400 nm. and 480 nm. (fig. 5b). Photomorphogenesis is the formation and definition of plants' tissues controlled by radiant energy — peaks at a wavelength of 660 nm. in the red band, and 735 in the far-red region (fig.5b). Photoperiodism is the development of plants in relation to the length of daily light periods.

Researchers have found that the red light of 660 nm. is the vital part of the energy spectrum which influences the photoperiodic response of plants (fig. 5b). Some scientist have concluded that all of the above plants' reactions can be guaranteed when sunlight is provided.[18]

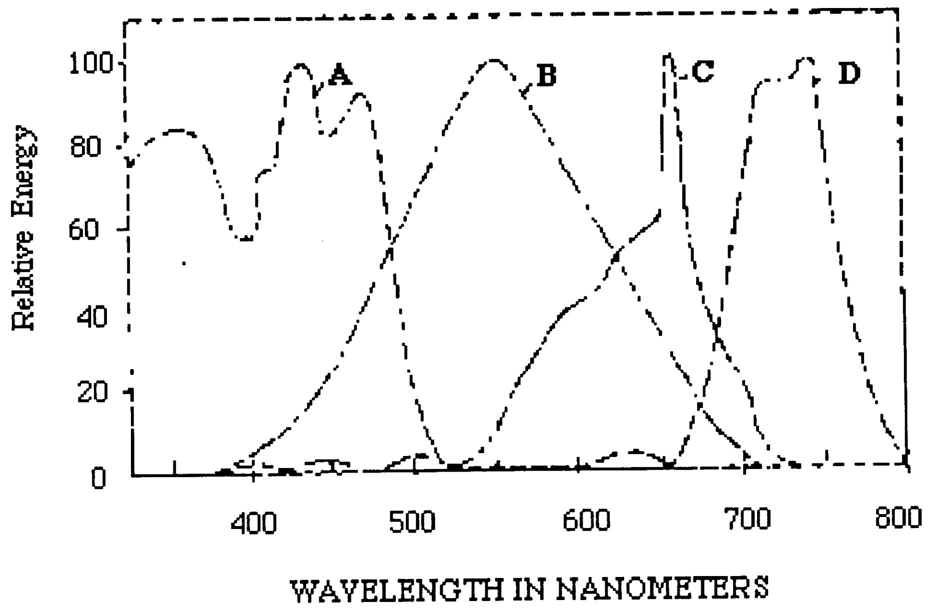


Figure 5b(A) Phototropic Response (B) Eye Sensitivity Curve
(C) Photomorphogenic Induction (D) Photomorphogenic Reversal

Figure 5c

BLUE SPECTRUM

Plants' Response	% Energy Needed For Growth
Photosynthetic Response (435 nm)	57%
Chlorophyll Synthesis (445 nm)	59%
Phototropic Response (400&480nm)	58% & 85%

RED SPECTRUM

Plants' Response	% Energy Needed For Growth
Photosynthetic Response (675 nm)	100%
Chlorophyll Synthesis (650 nm)	97%
Photomorphogenesis Response (660nm)	100%

The data above is an analysis of Figures 5a & 5b, which show the percentage of relative energy needed for photosynthesis, chlorophyll synthesis, photoperiodism, and photomorphogenesis response. Within the plant growth environment, the quality of daylight present is directly influenced by the physical properties of the light transmitting glazing. Hence, ability of the Lo_E glazing to transmit the correct percentage of energy in the blue and red spectrum is of utmost importance to the successful growth of crops within this facility.

Now, it is well documented that because of its energy transmitting properties, plants grow well under clear glazing. What is not known, is how good crops will grow from the energy transmitted through clear Lo_E glass. In order to set the record straight, an analysis was done for the energy transmission through 1/4" thick Lo_E glazing, and 1/4" thick clear glazing. The findings are as follows :

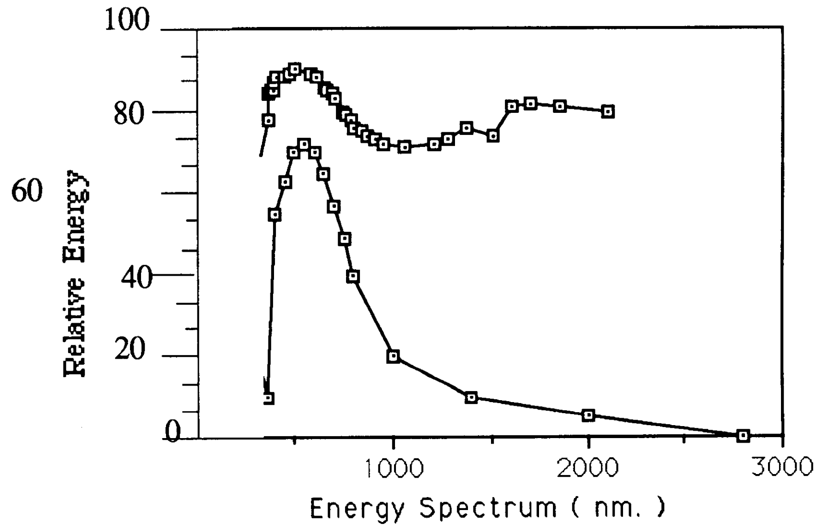


Figure 5d: A Comparative Analysis of Relative Energy Transmitted Through Cardinal 1/4" Thick Clear Glass, and, 1/4" Thick Clear Lo_E Glass_

Figure 5e : Relative Energy in the Blue and Red Spectrums Transmitted Through Cardinal 1/4" Thick Clear Glass, and, 1/4" Thick Clear Lo_E Glass

BLUE SPECTRUM

Plant response	% R E thr. Lo_E	% R E thr. 1/4" Clear
Photosynthetic Response (435 nm)	58%	87.5%
Chlorophyll Synthesis (445 nm)	61%	88.5%
Phototropic Response (400&480nm)	55% & 68%	88% & 89.5%

RED SPECTRUM

Plant response	% R E thr. Lo_E	% R E thr. 1/4" Clear
Photosynthetic Response (675 nm)	60%	85.75%
Chlorophyll Synthesis (650 nm)	65%	85.5%
Photomorphogenesis Response (660nm)	60%	85%

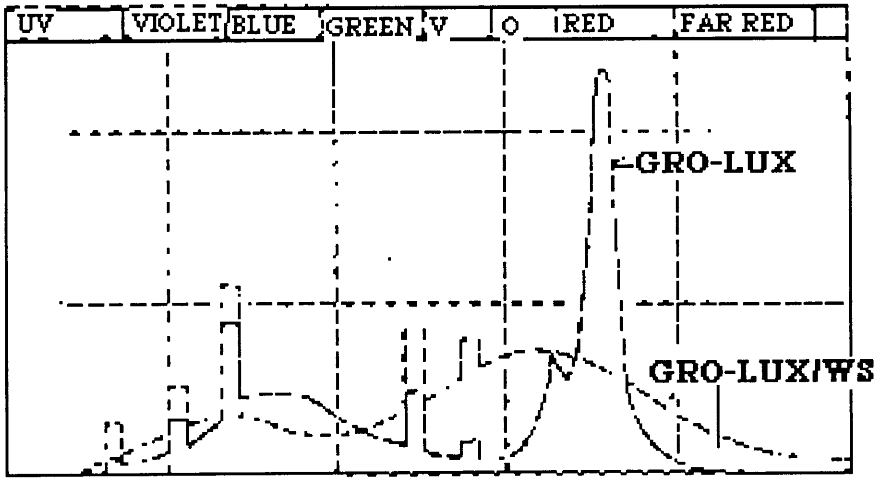
The data indicates that plants can grow quite well in the blue spectrum, under the available relative energy transmitted through the 1/4" clear Lo_E glazing and extremely good under 1/4" clear glazing. For both photosynthetic and chlorophyll response, the needed relative energy is exceeded by 1% and 2% for Lo_E, and by 30.5% and 29.5% for 1/4" clear glazing. However, for phototropic synthesis, Lo_E glazing falls short by 3% and 17% needed for optimum response in the 400 and 480 nm light spectrum. On the other hand, energy transmitted through the 1/4" clear glazing exceeds the requirements by 30% and 4.5% respectively.

In the red spectrum the situation is a bit different. The percentage of relative energy transmitted through the Lo_E glazing shows a deficit of -40%, -32%, -40% for photosynthesis, chlorophyll synthesis, and photomorphogenesis. For the same plants' response transmission through the 1/4" clear glazing also shows a deficit of 14.3%, 11.5%, and 15% respectively. Though the 1/4" clear glazing transmits a higher percentage of energy, it is important to discuss why Lo_E glazing was chosen over 1/4" clear glazing. First of all, one must remember that the components of energy are light and heat. So if the 1/4" clear glazing transmits a higher percentage of energy than the Lo_E, it follows that much more heat will also be transmitted. The primary objective of this design is to maintain an energy efficient plant growth environment. Secondly, Lo_E glazing is designed with properties that not only transmits daylight, but also minimizes the heat content of the entering daylight. Hence, the most logical choice of glazing was one that allowed the cooling loads to be held to a minimum.

The deficit of energy transmitted through the Lo_E glazing within the red spectrum implies that the energy will have to be occasionally supplemented for the corresponding red action spectrum. This supplimental red light will only be necessary when the interior energy levels fall below the minimum 100% relative energy needed for optimum growth. Figure 5f shows an example of supplimental lighting in the form of Sylvania's Standard Gro-Lux lamps. These lamps span over a 350 to 850 nm wavelength, and peaks to a relative energy of approximately 100% at 675nm in the red spectrum. If the plants are to receive the optimum photosynthetic active radiation, these lamps will have to be added to the lighting design in the plant growth facility.

Now, it is clearly known in the world of plant culture, that in the natural environment, without glass cover, plants will grow quite well at a light intensity of 1200 foot candles.

re 5f: Comparison of the Spectral Energy Distribution Curves of the Standard Gro-Lux And The Gro-Lux Wide Spectrum Lamps, Showing The Greater Amount Of Far-Red Energy From The Gro-Lux Wide Spectrum Lamps.



This is possible because the relative energy needed for plants' spectral response is perfect at 100%. It has also been previously stated that within the proposed plant growth environment there is a 40% defficiency red spectral light distributed over the plants when the light intensity is at 1200 f.c. So, if the Sylvania's Gro-Lux lamps (which are designed to distribute light in the red region) are turned on to suppliment the defficient 40%, it implies that the 100% of relative energy needed in the red spectral region will be satisified, and the interior lighting increase from 12000 fc to 2000 fc. Hence, the supplimental red artificial lighting will only be turned on when the interior lighting levels fall below 2000 f.c.

The time period during which these lamps will be turned on could have a negative or positive impact on the cooling loads.

During the day when there are long periods of no sunlight, these lamps will be turned on at night to compensate for the insufficient amounts of energy present in the plant growth environment. Under these conditions the artificial lighting will be turned on for an additional four hour period per day. Since on an average day the light period last for twelve hours (8 hours daylight and 4 hours supplimental lighting), it follows that during days when sunlight is totally absent the light period will last for a total of sixteen hours, and the dark period will last for eight hours.

CHAPTER 6 :

DAYLIGHT DESIGN FOR THE SEEDLING ROOM

As a result, seed germination and its development into seedling must be conducted in a controlled and protected environment.

For most vegetables, the presence of light at the germination stage is quite infrequent. In this proposed food production facility, seeds will be cultured within the controlled environment of a seedling room.

The most important phase of a plant's development is that stage from germination to seedling. It is at this point, from dormant seed to growing seed, that crops are most capable of being harmed by seedling diseases such as *Pythium, Rhizoctonia, and Phytophthora* caused by the presence of pathogens.

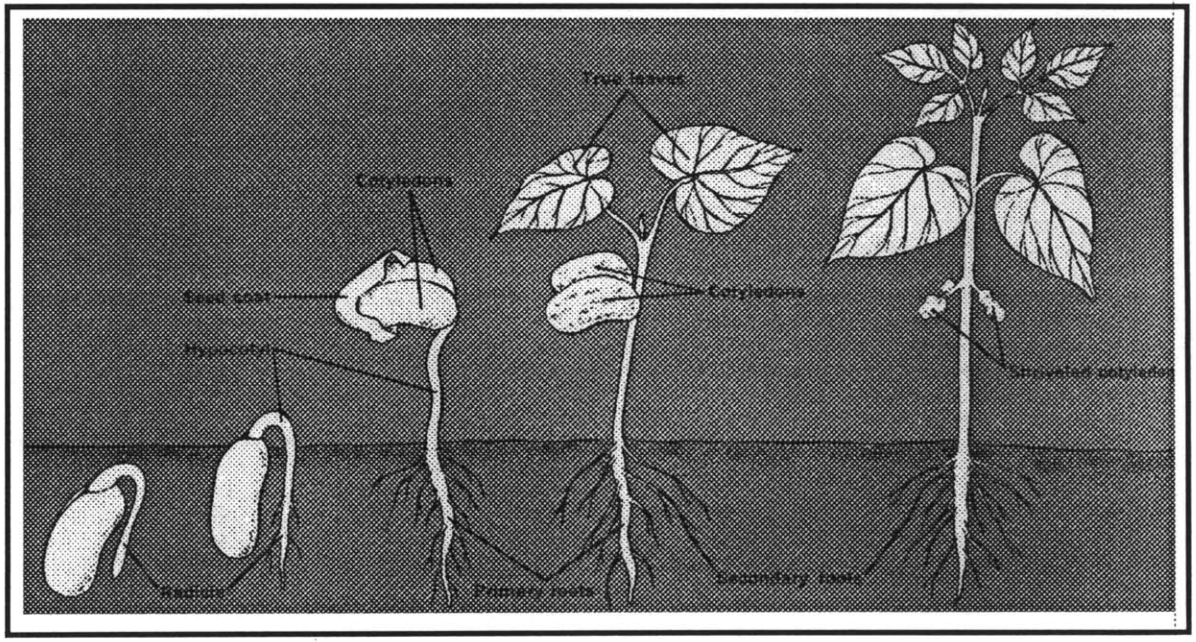


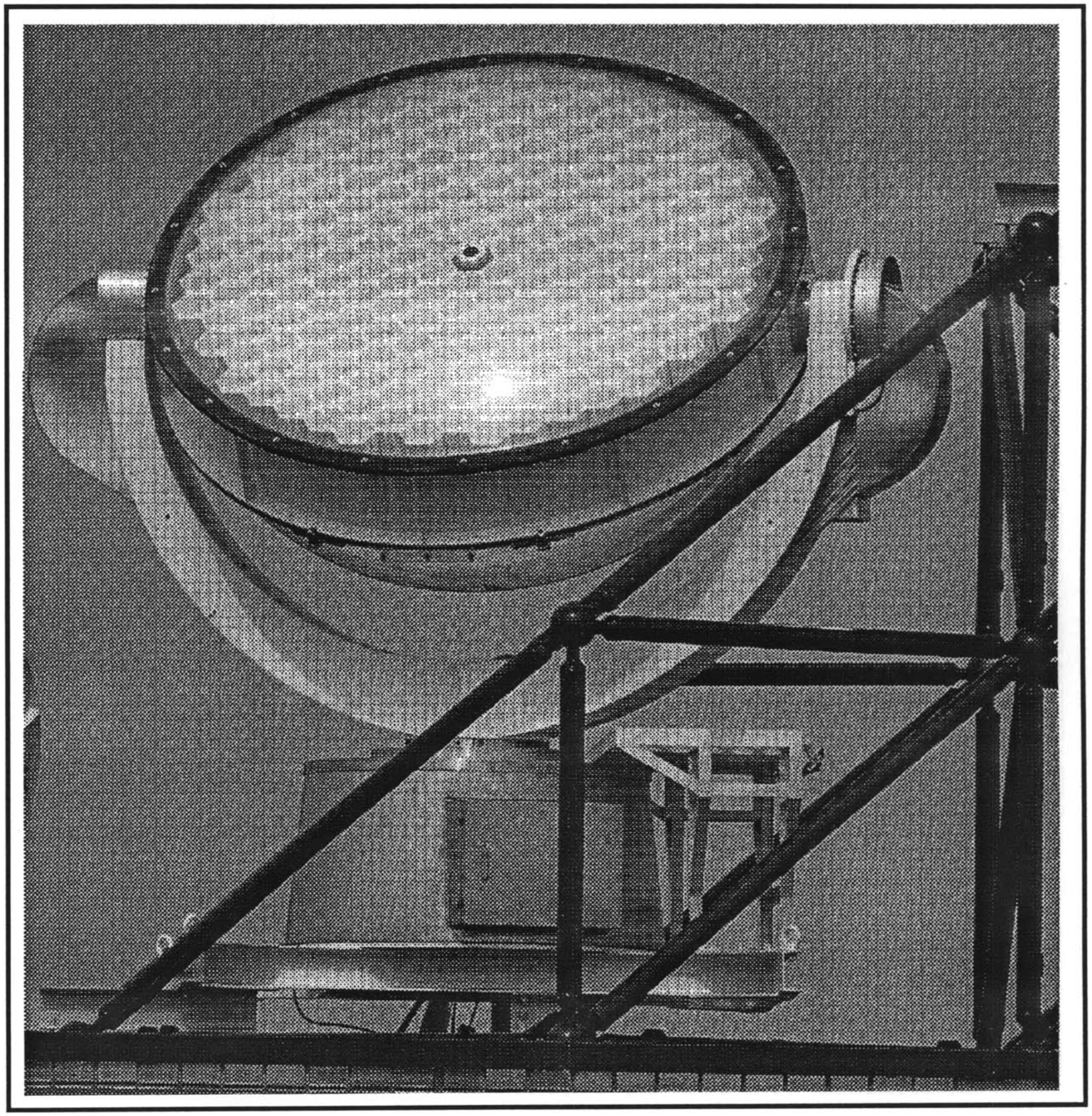
Figure 6a: The Earliest Stages of a Plant's Development

While there, the seeds will be planted in growing troughs, unexposed to light, for the period of germination. On most occasions the first part of the seed to appear is the radicle, which grows downwards. It is followed by the hypocotyl, which generally lengthens and lifts the cotyledons and plumule out of the seed (fig. 6a). As germination continues, cells at the tip of the radicle and the plumule divide rapidly. When the seedling emerges as an independent plant, germination is completed.[20] Compared to conventional agriculture, germination of seeds will occur at a greater rate in this facility.

Once germination is completed and the seedlings appear, the developed seeds remain in the seedling room until they are large enough to be transplanted to the plant growth environment. During this period, light will then be introduced to the seedlings. While the intensity need not be high, the distribution must be uniform over each growing tray.[10] Consequently, the Himawari System (discussed in Chapter 3), was selected to supply photosynthetic active radiation to the seedlings. The Himawari's ability to provide an even distribution of light, free of any ultraviolet and infrared rays was a major factor in determining its selection. This ability for the Himawari to supply light free of infrared and ultraviolet rays implies that the quantity of light necessary for optimum plant growth would be less when optical lighting is supplied, compared to direct sunlight. For example, seedlings thrive in the natural environment at 1100 to 1200 foot candle. However, it has be proven that seedlings' quality and growth rate will improve when supplied with Himawari lighting levels of approximately 700 fc (7560 lux).[21]

The Himawari unit selected is called the XF-160/190. Compared to the unit shown in the schematic design development, this unit is much more improved.

Figure 6b: XF 160/196 Himawari Unit



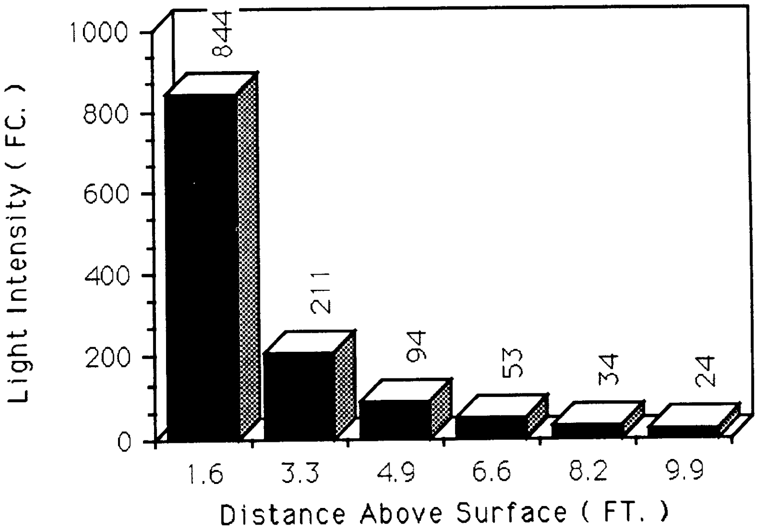
First of all, the D-200/L19 discussed in chapter 3 has nineteen lens. At the end of each lens is the input end of a bundle of 37 optical fibers clad in a quartz core which admit focused solar rays and transmit the light to the other extremity. The inefficiency of the optic fiber cladding, coupled with uneven rays that penetrated the acrylic globe, reaching the fresnel lens, led to the the development of the XF-160/196 unit (fig 6b).

Compared to the D-200/L19, this unit has 196 lens. At the end of each lens is the input end of a single light transmitting optical fiber — efficiency is greatly improved. In addition, the unit has the design of a half globe. This means that the sun's parallel rays now travel less distance to reach the fresnel lens. From the 196 optical fibers it is possible to have twenty-eight bundles of seven optical fibers, seven bundles of twenty-eight fibers, one bundle of one hundred and ninety-six fibers, or any varying combination.

Figure 6c: Data and Graphs of XF-160/196 Himawari Unit Characteristics

distance above surface	light intensity	distribution area
1.6 FT.	844 FC.	1.4 SQ FT.
3.3 FT.	211 FC.	5.5 SQ FT.
4.9 FT.	94 FC.	12.4 SQ FT.
6.6 FT.	53 FC.	22.1 SQ FT.
8.2 FT.	34 FC.	34.6 SQ FT.
9.9 FT.	24 FC.	49.7 SQ FT.

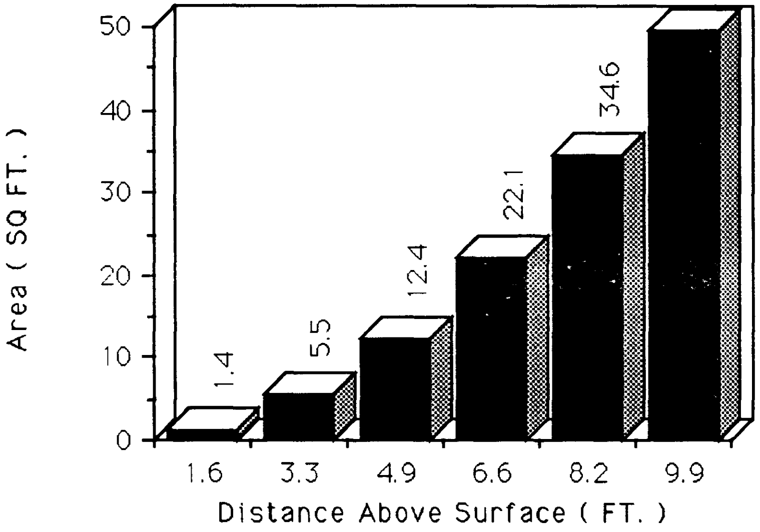
Fig. 6c' Distance Above Surface Vs. Light Intensity



The quantity of daylight transmitted by the Himawari unit is dependent upon the amount of optical fibers in a bundle, and the distance above a surface. Figure 6c shows that for a bundle of seven fibers, the XF-160/196 will supply daylight that has an area of 201 sq. in., at an intensity of 8440 lux (approx. 781 fc), 0.5 m (20 in.) above a surface. The light leaves the output end of the optic fibers at 45 deg., and takes the form of an ellipse when projected unto a surface. (Fig. 6d).

Because of the unique features of the Himawari unit discussed above, it was decided that a light intensity of approximately 940 fc will uniformly distributed over the young plants within the seedling environment. This light intensity of approximately 940 fc, on a horizontal surface, has several implications. Firstly, since one bundle of seven optic fibers, mounted 5 ft above a surface, is capable of transmitting a light intensity of approximately 94 fc, it implies that ten bundles of seven optic fibers would be needed th maintain a constant illuminance of 940 fc.

Fig:6c"Dist. Above Surf'e Vs. Area of light on Surf'e



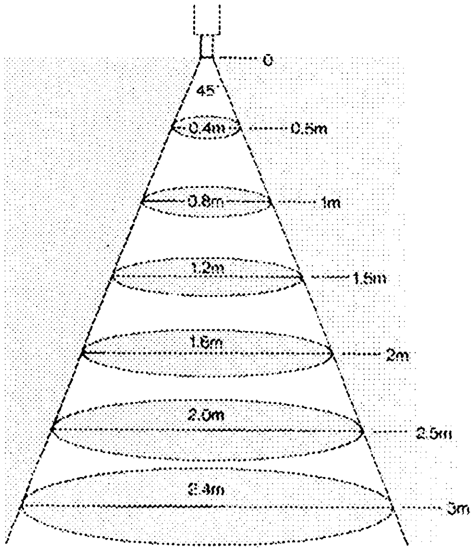


Figure 6d: Daylight at Out-put End of Optic Fiber

Furthermore, this 940 fc. is designed to be distributed over an elliptical area of 12.4 sq. ft, with a minor axis of 12 inches and a major axis of 4 ft. (fig. 6e).

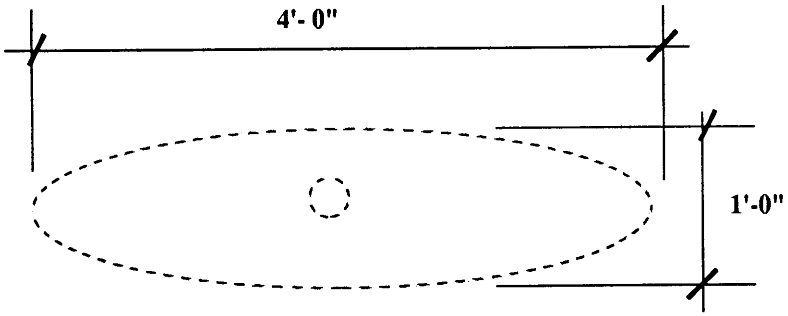


Figure 6e

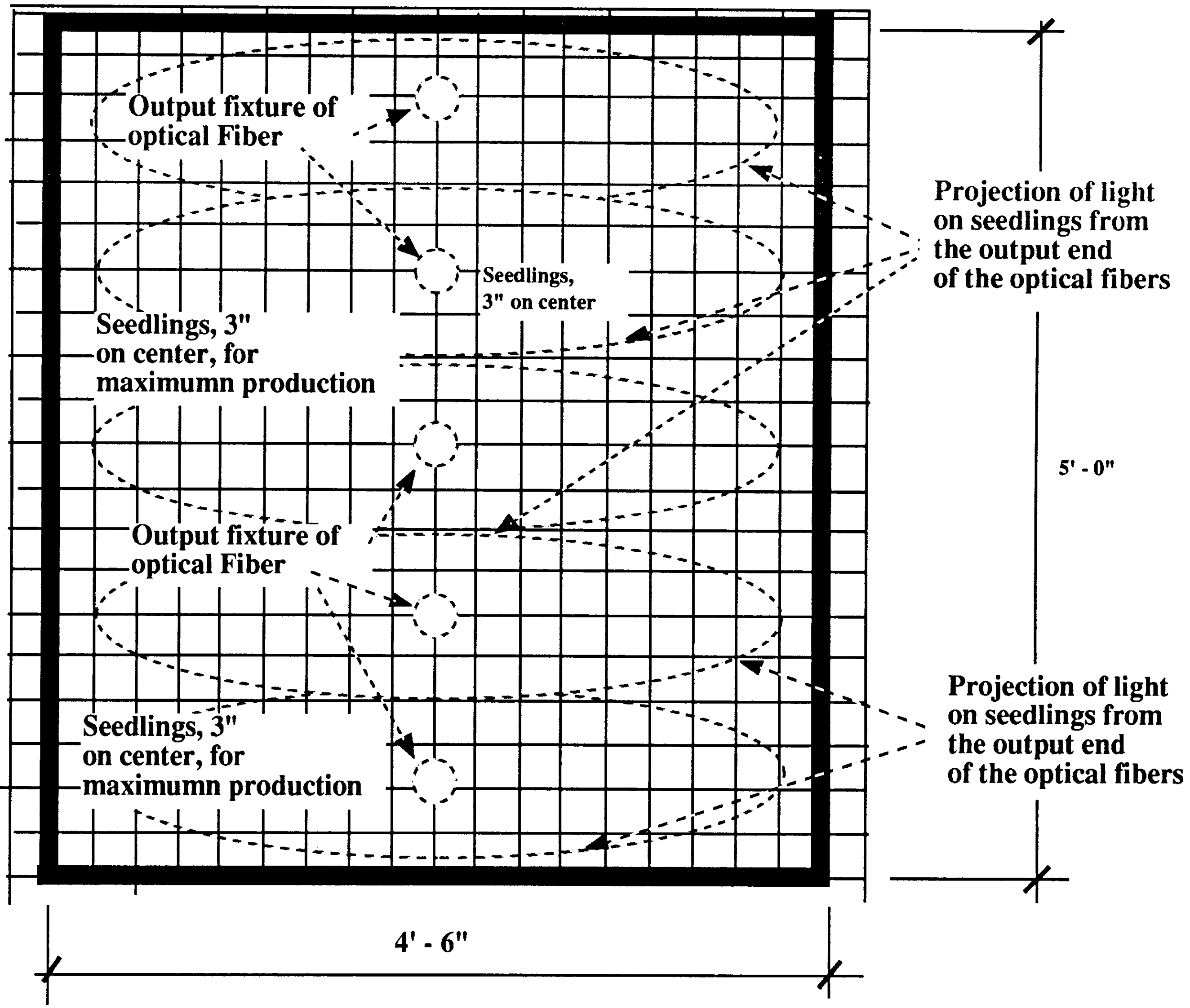
Now it has already been established that the XF-160/196 has one hundred and ninety-six optic fibers, and ten bundles of seven fibers are needed to maintain a uniform illuminance of 940 fc. So, five bundles of seventy optic fibers, respectively, will be needed for constant light distribution over one tray of seedlings; eighty bundles of seventy optic fibers for the sixteen seedling trays; 5600 optic fibers all together.

The result is 28.57 XF-160/196 Himawari needed to supply photosynthetic active radiation to the seedlings within the young plants' environment. It was decided that this design will specify 30 XF-160/196 units. The optic fibers from the remaining 1.43 Himawari units will be used to supply daylight to areas on the seedling trays that is out of the path of elliptical light irradiance. Whenever there is overcast skies, the seedlings will receive photosynthetic active radiation from energy efficient artificial lighting.

The plan of a typical seedling tray shows that most of the plants will receive an even distribution of light (fig. 6f). In the design of this seedling tray approximately, in which young crops are planted three inches on center, 340 seedlings can be accommodated when maximum production is desired.

This means that from the sixteen trays, it is possible to transplant 5,440 mature seedlings to the plant growth environment — quite sufficient for continued crop production within this facility. As a result, the seedling environment on the ground floor of the hydroponic facility will provide mature seedlings for the seedlings for the ground, first and second floors. The seedlings will be lifted to the first and second floor plant growth environment.

Figure 6f: Layout of a Typical Seedling Tray



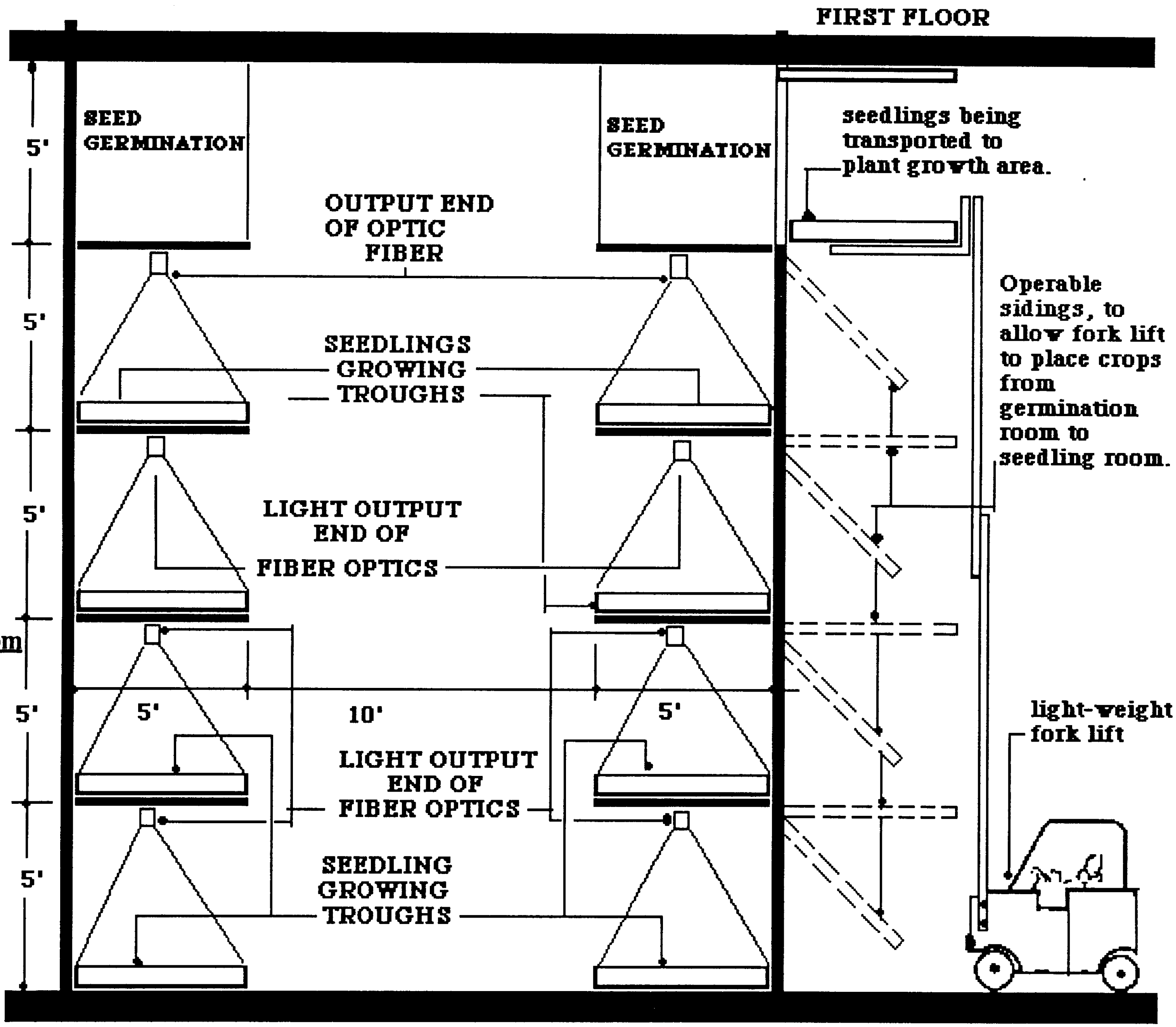


Figure 6g: Section Through Seedling Room

The section through the seedling room shows the concept of multi-level growing trays (fig. 6g). The idea here is to maximize the use of available floor to ceiling height, and leave the floor space solely for plant growth. In this scheme, the output ends of the optic fibers are mounted approximately five feet above each seedling tray. The section shows four levels of growing trays, and two upper levels, designed for seed germination. Once seedlings are mature enough to be transplanted to the plant growth environment, horizontal operable doors on either sides of the seedling room are lifted and the mature seedlings are removed by a hydraulic lift.

CHAPTER 7 :

THERMAL CONTROL WITHIN THE PLANT GROWTH ENVIRONMENT

Temperature, along with photosynthetic active radiation, and nutrients, is one of the most important environmental factors affecting the growth of plants. The minimum and maximum temperature to support plant growth generally lies between 40 and 97° F.[18] However, the temperature at which optimum growth occurs varies with the type of crop. For example, cool crops such as spinach, lettuce, and cabbage will grow well at temperatures between 65 and 75° F. On the other hand, warm-season vegetables such as tomato, eggplant and cucumber will grow great at temperatures between 75 and 95° F. Either very high or very low temperatures can often lead to the death of plants. High temperatures at critical times during plant growth can cause flower abortion and reduce yield.[22]

In a controlled environment, the temperature does not only influence plant development and growth, but also directly affects the degree of control of other environmental factors such as relative humidity. It has already been established in Chapter 2 that a humidity range between 50% and 70% is satisfactory for optimum plant growth. Before a decision was made on the cooling equipment to handle the cooling loads it was decided that the indoor temperature and relative humidity design conditions will be maintained at 75° F (DB), and 60% RH, during the day. During night time the outdoor temperature on the island of Trinidad drops to an average of 72° F (DB). Each day this temperature drop occurs at about 7:00pm.

Since the primary concern of this proposal was to present the most energy efficient design for each component of this food production facility, it was first decided that a passive approach would be the best solution to provide cooling for the plant growth environment. Consequently, studies were conducted into the possible application of Evaporative Cooling. When compared with refrigeration cooling, evaporative cooling was much less expensive. The evaporative process basically removes sensible heat and replaces it with latent heat of equal amounts. As water changes from a liquid to a vapor, the indoor dry bulb temperature falls, but the moisture content increases.

Both direct and two stage evaporative cooling systems were investigated. Each system is fundamentally simple. Some direct evaporative cooling systems are manufactured and sold in a compact box. A fan draws ambient air through wet fiber pads, cooling the air by evaporation before blowing it into a space. The used air is then exhausted to the outside. On the other hand two stage evaporative cooling is only achieved by precooling air without humidification, before further cooling by evaporation. The first stage can be a cooling tower. The heat exchanger then uses the cool fluid from the first stage to precool the outside air entering the second stage evaporative cooler. The cool air then flows through the space and out through sources of heat gain.[23]

The success of direct and two stage evaporative cooling is directly dependent upon the outdoor relative humidity and wet bulb temperature. In reality, the outdoor wet bulb temperature governs the ultimate dry bulb temperature of the air discharged from the evaporative cooler. Direct evaporation cannot cool below the wet bulb temperature, and the process stops when the relative humidity reaches 100%. Two stage evaporation cannot cool below the difference between the dry bulb and wet bulb temperature. During very hot and humid outdoor conditions, evaporative cooling will not provide the desired comfort for the plants.

Figure 7a shows the approximate average annual outdoor weather condition for each month of a typical year on the island of Trinidad. The average annual wet bulb temperature is 75.2^0 F, and the average annual outdoor relative humidity is 66.3%. In addition, data from Trinidad's meteorological office has indicated that the average outdoor relative humidity for a typical year during the time period in which cooling is needed within the plant growth facility, 7:00 am - 7:00 pm, would be approximately 72.5%. During the dark period within the plant growth environment, 7:00pm - 7:00 am, the average annual relative humidity would be approximately 90.6%. The above data is significant for many reasons. First of all, direct evaporative cooling was immediately eliminated because it was already stated that this system cannot cool below the outdoor wet bulb temperature.

As figure 7a indicates, the approximate average outdoor wet bulb temperature for a typical year of 75.2^0 F is more than the indoor design dry bulb condition of 75^0 F. Now, it has already been stated that for both direct and two stage evaporative cooling, sensible heat is removed, and replaced with latent heat, thereby raising the moisture content of the air. In other words, as the indoor dry bulb temperature drops, the indoor relative humidity increases. Therefore, if the average outdoor relative humidity enters the two stage evaporative cooler at 72.5%, it would imply that the conditioned air entering the plant growth environment would have an indoor relative humidity much higher than 72.5%. It is most important to note that plants will grow best when the indoor relative humidity is within a region of 40% to 70%.

	January	February	March	April
Outdoor	82F(DB)	83.6F(DB)	84F(DB)	87F(DB)
	66.5%RH	59%RH	59%RH	56.5%RH
	73F(WB)	72.5F(WB)	69.5F(WB)	74.5F(WB)

May	June	July	August
86F(DB)	84F(DB)	85F(DB)	86F(DB)
64%RH	70.5%RH	68.5%RH	70%RH
75.5F(WB)	76F(WB)	76F(WB)	78F(WB)

September	October	November	December
86F(DB)	85.6F(DB)	82.8F(DB)	83.6F(DB)
68.5%RH	70%RH	74.5%RH	68%RH
77.5F(WB)	77.75F(WB)	75.8F(WB)	75F(WB)

Figure 7a.

	Outdoor	Indoor
January	82F(DB)	75° F (DB)
	66.5%RH	91% RH
	73F(WB)	
February	83.6F(DB)	75° F (DB)
	59%RH	88% RH
	72.5F(WB)	
March	84F(DB)	75° F (DB)
	59%RH	71% RH
	69.5F(WB)	
April	87F(DB)	75° F (DB)
	56.5%RH	94% RH
	74.5F(WB)	
May	86F(DB)	75° F (DB)
	64%RH	100% RH
	75.5F(WB)	
June	84F(DB)	75° F (DB)
	70.5%RH	100% RH
	76F(WB)	

Figure 7b

Figure 7b shows some examples of the resulting indoor condition when two stage evaporative is used, given the average outdoor conditions for Trinidad. The results clearly show that though two stage evaporative cooling will provide the required sensible cooling, it will not deliver the necessary latent cooling. However, though evaporative cooling will not work well in Trinidad due to the very high outdoor wet bulb temperatures and high relative humidity, the climatic conditions of several other equatorial climates are quite opportune for evaporative cooling. Consequently, the next step was to investigate the possible use of refrigeration cooling.

Once the indoor design conditions were finalized, the cooling loads for the worst outdoor condition during a typical year was then calculated. A very thorough analysis of the heat gain through the Lo_E glazing, at each floor was then conducted (see appendix 2).

The results of the heat gain study revealed that during the month of December, both the ground and second floors of the plant growth environment incurred the greatest amounts of solar heat gains. This was due to an average outdoor condition of 83.6° F (DB), and 75° F (WB). For calculation purposes, the heat gain on the ground floor was chosen. The following is the procedure for calculating the size of the refrigeration equipment :

a. Outdoor Design Condition = 83.6° F (DB), 75° F (WB)
Indoor Design Condition = 75° F (DB), 60% RH
Number of Occupants = 15
Occupants Per Floor = 5
Activity = Harvesting

	Sensible Heat	Latent Heat
Solar Gains	= 450,625 Btuh	
People	= 5 x 405	= 5 x 875
	= 2,025 Btuh	= 4,375 Btuh

Room Sensible Heat (RSH) = 452,650 Btuh

Room Latent Heat (RLH) = 4,375 Btuh

So, Sensible Heat Factor (SHF) $= \dfrac{\text{RSH}}{\text{RSH + RLH}}$

$$= \frac{452{,}650 \text{ Btuh}}{457{,}025 \text{ Btuh}}$$

$$= 0.99$$

On the psychometric chart (fig. 7c), a line is drawn between the fixed "bulls-eye" (80 DB, 50% rh) and the value of 0.99 on the SHF scale, at the upper right edge of the chart. This is called the "SHF line."

b. Point A on the psychometric chart is the condition of the "used" air within the plant growth environment, as it is returned for processing : 75° F (DB), 60% RH.

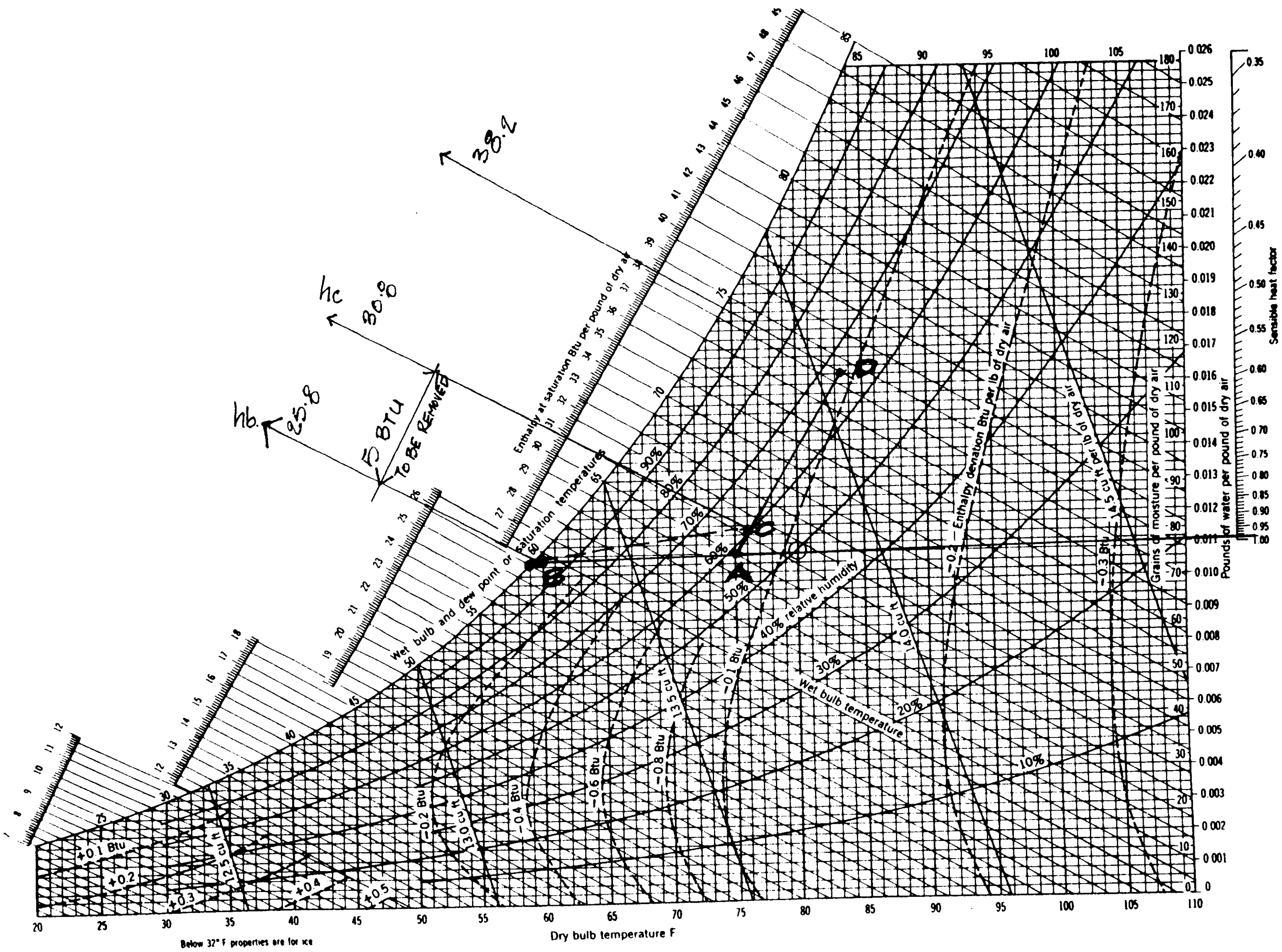
c. The next step was to decide how much cooler the supply air should be than the return air. To avoid uncomfortabl drafts, most engineers and architects design the supply temperature at 20° F, or less below the space's air temperature. For this project the supply temperature will be 15° F below the space's air temperature.

d. Quality of air to be cooled $= \dfrac{\text{RSH}}{1.08 \text{ x \^{}t}}$

$$= \frac{456{,}700 \text{ Btuh}}{1.08 \text{ x } 15^\circ \text{ F}}$$

$$= 28,\ 191 \text{ CFM}$$

e. 10% Outdoor Air; 90% Recirculated Indoor Air. So, point C on the psychometric chart = 10% (83.6) + 90% (75) = 76° F (DB), 60%RH.



Fifure 7c: Psyochometric Chart

f. Point D on the psychometric chart (the outdoor condition)
= 83.6° F (DB), 75° F (WB)

g. Point B on the psychometric chart (the condition of air entering the room) =60° F (DB), 59.5° F (WB)

h. So, Enthalpy, the total amount of sensible and latent heat in the air = 5 Btu/lb of dry air

i. Therefore, the cooling equipment must remove a grand total of heat (GTH) = 4.5 x cfm x (h_c - h_b)
(where 4.5 is a constant = 60 min/h x 0.075 lb/ft^3 average air density) GTH = 4.5x28,191cfmx5btu/lb
GTH = 608,925.6 Btuh
However, the size of the required refrigeration unit is specified in "tons", where 1 ton = 12,000Btuh
So, refrigeration required for the Ground floor
= 608,925.6/12,000
=50 tons

j. Similar calculations were done to determine the required refrigeration for the second floor = 50 tons, and
the first floor = 40 tons

Using a C.O.P. of 4.0 for the largest A/C unit to determine the required power, it was discovered that a peak total of 125 kw/hr was needed to drive 140 tons of refrigeration for the three floors of the plant growth structure. But since the peak condition only happens about 1/3 of the operation time, it was best to design for 2/3 the amount of power required (2/3 x 125 = 83.30 kw). This is possible because the thermal inertia of the materials within the plant growth facility can store cooling to supplement heavy loads during peak conditions.

Hence, the refrigeration cycle operating for twelve hours per

would need = 12hrs x 83.30kw

= 1,000kwh/day.

= 30,000kwh/month

For an economic feasibility study, three refrigeration companies were consulted. For each company, the cost of 140 tons refrigeration is as follows:

1. United Products, Baltimore, MD (Carrier)
   = $87,000.00 (approx.)
2. G.F. Morin Co., Maryland. (Multistack)
   = $60,000.00 (approx.)

3. Dectron, Canada = $284,000.00 (F.O.B.)

(All the above prices are only the cost of the refrigeration equipment.)

With the advent of refrigeration cooling the next logical step was to determine the source of power to fuel the refrigeration equipment. Once again, the objective was to present the most economic and energy efficient solution. As a result, several passive systems such as wind energy, pv systems, natural gas electricity, and co-generation, were all researched. The findings are as follows :

PHOTOVOLTAIC SYSTEMS

The research was then directed towards the photovoltaic industry, and companies such as : Integrated Power Corporation, Photron Inc., Photocomm Inc., Solarex Corporation, and, the Solar Energy Research Institute were contacted for advice and information. Once again, the economic reality of $3,000. to $4,000. per kw. of power determined the impossibility of using photovoltaic systems.

NATURAL GAS ELECTRICITY

Trinidad is one of the few Caribbean Island with oil, and with the drilling of oil, comes natural gas. Consequently, 90% of electricity in Trinidad, is generated from natural gas. The cost of purchasing electricity for industrial use is as follows :

1.60 cents (US) per KWH for the first 50,000KWH used in any month.

1.53 cents (US) per KWH for the next 200,000KWH - 500,000KWH used in any month.

COST OF ELECTRICITY TO PRODUCE ENERGY FOR PLANT GROWTH STRUCTURES :

First 50,000 KWH @ 1.60 cents per KWH= $800.00

Additional 40,000 KWH @ 1.53 cents per KWH = $612.00

Total cost of 90,000 KWH/month for all three plant growth structures = $1,412.00

Total cost of 30,000 KWH/month for all one plant growth structures = $471.00

CO-GENERATION/ABSORPTION COOLING

During the research of water, steam and gas co-generation, "Absorption Cooling"— cooling with heat, was discovered as a potentiallly inexpensive source of energy . The technology seemed to be quite attractive, because the heat needed for cooling was free. The following analysis is based on an Absorption Cooler made in modules of ten (10), by Yazaki :

ANALYSIS : Totally passive solar air conditioning system.

1. The system rejects heat through a cooling tower.
   In this system it was proposed
   that the cooling towers be abandoned, and the heat
   be recirculated to energize the
   hot water for the water fired chillers.

2. Now it was previously stated that 140 tons of refrigeration was needed for cooling, and the machine has a COP of 0.70. Consequently, the energy needed to fire the generator = 140 tons/0.70 = 2,400,000.00 Btuh

3. One of the major reasons why the vertical glazing was not designed for either the east or west walls of the plant growth structures, was due to the tremendous amount of solar gain on these vertical planes. Both the east and west walls have a total square foot area of 10,600. The first and second floors have a total of 6,000 sq. ft light reflective surfaces. It was proposed that all these vertical walls and horizontal floors be constructed as 'Trombe' (thermal) walls and floors. Heat gain studies showed that for each day, from 7:00am to 5:00pm, for each month of the year, it was possible to harvest an average of 2,000,000 Btuh, from these surfaces. This, as well as the reclaimed heat mentioned above, would provide sufficient energy to power the generator that provide hot water toenergize the water fired chillers.

However, both the cost of 140 tons of refrigeration equipment = $161,000.00 ,and the machine's COP of 0.70, makes "absorption Cooling", very difficult to compete the cost of with natural gas electricity.

WIND ENERGY

Figure 7d:Mean Wind Speed For Specific Periods Of The Day For Each Month Of 1987.

(ALL WIND VALUES IN MILES PER HOUR.)

East/Central East Coast of Island

	8:OO A.M.	2:OO P.M	8:00 P.M.	AV.	AV x 1.75
JAN	8.3	27.45	13.3	16.35	28.6125
FEB	6.75	26.8	11.7	15.08	26.39
MAR	11.03	27.45	13.5	17.33	30.3275
APR	17.6	28.8	16.2	20.86	36.505
MAY	14.2	27.2	13.3	18.23	31.9025
JUN	10.6	25.4	13.7	16.56	28.98
JUL	9.2	20.7	10.1	13.3	23.275
AUG	5.6	23.4	9.45	12.82	22.435
SEP	7.4	21.6	9.2	12.73	22.2775
OCT	4.5	21.4	6.75	10.88	19.04
NOV	6.3	18.9	6.75	10.65	18.6375
DEC	5.2	23.4	8.1	12.23	21.4025

Due to constant availability of wind on the east coast of the Island, Wind energy seemed to be a very good choice. For this thesis study, Toco, a small village on the east coast of the Islandwas selected as the proposed location for this project. Toco is located approximately twenty miles from its nearest major city, and about thirty-five miles from the Capital, Port-of-Spain. Toco, with an annual average wind speed of approximately 25 mph, is an ideal site for a wind farm to generate electrical or thermal power (fig. 7d). These very strong wind conditions present on the eastern coast of Trinidad, propelled the research of wind energy into great depth. To support the research many organizations and commercial companies such as the Department of Wind/ Ocean Energy Technologies, Northern Power Systems, U.S. Windpower, Howden Wind Park, Flowind Corporation, and, Westinghouse were solicited for information and advice. The information received was based on both Vertical and Horizontal wind turbines.

Generally, the cost of wind energy at $1,000.00/kw, appeared to be quite favorable for generating power. For example, total cost of producing the daily peak of 83.3 kw, at $1,000./kw for each of the plant growth facility would be $83,300.00. So, the pay-back period, based on a constant amortization, for a wind energy system to generate power for each of the plant growth facility would be 14.7 years. This figure can be found through dividing the one time cost of the wind by the cost electricity for one year ($83,300./$5,256.). However, many of the island and countries within the equatorial climate region do not have natural gas, and therefore cannot afford to sell electricity as cheaply as Trinidad. If the average cost of electricity in many countries is 10 cents/kwh, it would imply that the monthly electric bill for one of the plant growth structure in an island other than Trinidad would be $3,000.00. The cost of electricity for one year would be $36,000.00. Hence, the pay-back period for a wind energy system to generate power to run the HVAC system of one plant growth structure in an island where the average cost of electricity is 10 cents/ kwh, would be 2.3 years ($83,300./$36,000.).

Though the cost of electricity is fairly inexpensive when compared with other islands, wind energy is being proposed as the best of all the systems analysed above to power the refrigeration equipment that will provide the necessary cooling within each of the plant growth structures. Another factor that has made wind energy a very good choice is the fact that power can be generated during the day as well as during the night. Hence, the wind system will also be used to power the fans that blow the cool humid air through the plant growth environment during the dark period of the plants' day.

Each day around 7:00 pm the outdoor dry bulb drops to approximately 75° F. In addition the average outside dry bulb temperature during the dark period, 7:00 am - 7:00 pm, is approximately 73° F, and the average outdoor relative humidity is 90.6% during this period. The fact that light is not present during the dark period within the plant growth environment does not mean that the controlled environment should not be maintained. In order to maintain optimum plant growth, a controlled plant growth environment should be maintained at all times of the day. However since it was decided that the refrigeration equipment will only provide cooling during the day it meant that plant comfort at night had to be secured through an alternative system. Now since the average outside dry bulb temperature during the dark period already as low as 73° F, the best way to take care of the very high outside average relative humidity is to blow a lot of night time air through the plant growth facility. In this scheme, even though relative humidity entering the plant growth environment would be high, the air movement will keep the plants healthy enough to maintain good growth.

CHAPTER 8 :

AQUACULTURE FACILITY

Aquaculture is the production, processing, and marketing of biological organisms from aquatic systems.[24] Although a relatively new field of food culture in Trinidad, and the Caribbean, aquaculture has been in existence for several thousands of years in China, Japan, and elsewhere in the Far East.

In Trinidad, the traditional fishing industry has been suffering from many problems. Firstly, there are the conflicts with Venezuela's fishermen. Geographically, Trinidad lies off the northeast coast of Venezuela and is separated from this island by the Gulf of Paria to the north and the Serpent's Mouth to the south. For as long as there have been fishing activities in these two bodies of water, there have been conflicts between Trinidad's and Venezuela's fishermen. Venezuela officials have claimed ownership of the fishing waters described above. As a result fishermen from Trinidad must obtain a permit from Venezuela in order to fish in these waters. In 1986, fishermen from Trinidad operating off the southwestern peninsula asked the Trinidad government to renegotiate the Fishing Agreement with Venezuela to increase the fishing permits. Only sixty of the two hundred plus boat owners on the southwestern peninsula had permits to fish in those waters. Since 1986 the fishing permits have been increased, but the future of Trinidad's fishing industry could very well lie in the hands of Venezuela officials.

Secondly, the traditional fishing industry in the Caribbean and other Equatorial Countries has not been able to keep up with population growth. The result over time has been fish degradation due to overfishing. Hence, the development of a stable aquaculture industry to supplement traditional fishing is of vital importance to the present and future dietary needs of a growing population.

From the research conducted on Trinidad's very small aquaculture industry it was quite clear that inadequate progress has been made in establishing scientific research on habits, breeding and commercial production of fish, and other marketable aquatic products. In most cases the aquaculture industry is limited to the growth of tilapia. For example, two major sea food diets, shrimp and cascadu are still being imported into Trinidad. Although these aquatic species are being cultured in Trinidad, the infrastructure for their production is not adequately developed to meet the market demand.

This thesis proposes an aquaculture facility in which aquatic species will be grown in a controlled environment. The major objective of the controlled environment is to grow fish food at a greater rate, and in larger quantities than traditional fishing. One of the prime considerations in designing a controlled environment is to present a facility in which all aquatic species will be protected form perils of the natural environment such as excessive flooding, and droughts. The very important environmental parameters such as temperature and photoperiod will be carefully controlled to maximize the end product.

Several kinds of water facilities may be needed for intensive aquaculture. The kind of facility constructed will depend on the size of the culture and the type of aquatic program to be followed. Commonly used structures include ponds, raceways, tanks, and aquariums. This proposed design solution will concentrate on pond culture.

The ponds will be designed in such a manner that they can be converted into raceways whenever shrimp will be grown. In this thesis, a pond is used to describe any size of earthen structure for holding a standing body of water that has very little or no flow. Generally, the type of fish pond gets its name from the aquatic activity within each pond. The types of ponds considered in this thesis are as follows :

1. Rearing pond : A small pond in which sack fries are placed for growing into fingerlings.
2. Growing Pond : A pond in which fingerlings are placed to be grown into mature fish.
3. Spawning Pond : A small pond in which broodfish are placed for spawning.

At the opening stages of this proposed aquaculture facility fish eggs will have to be bought from another hatchery facility. Once the purchase has been made, the eggs are then taken to the hatchery where they will be placed in incubators for hatching. The proposed design of the hatchery presents a solution in which incubator trays are placed on a vertical conveyor system (fig. 8a). Once the eggs are placed in the incubator, the trays will begin to move upwards in the vertical conveyor. The system is uniquely designed so that one oscillation of each incubator tray on the conveyor will be the exact time period for the eggs to hatch. At the second floor of the hatchery there is a control center that is used for research, meetings, and all administrative activities related to the aquaculture facility.

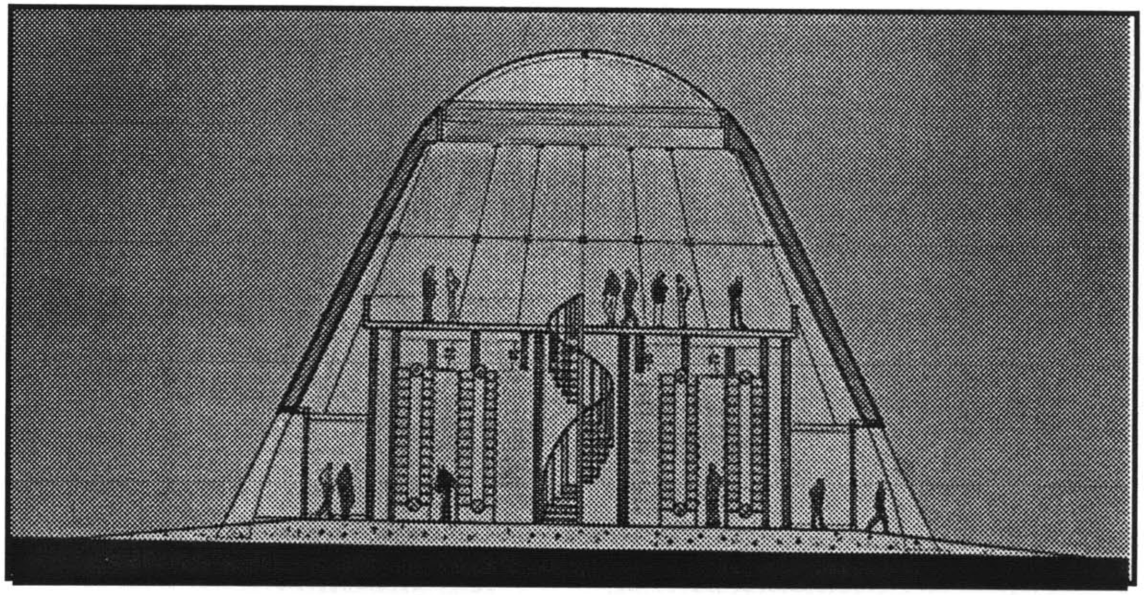


Figure 8a' : Section Through The Hatchery

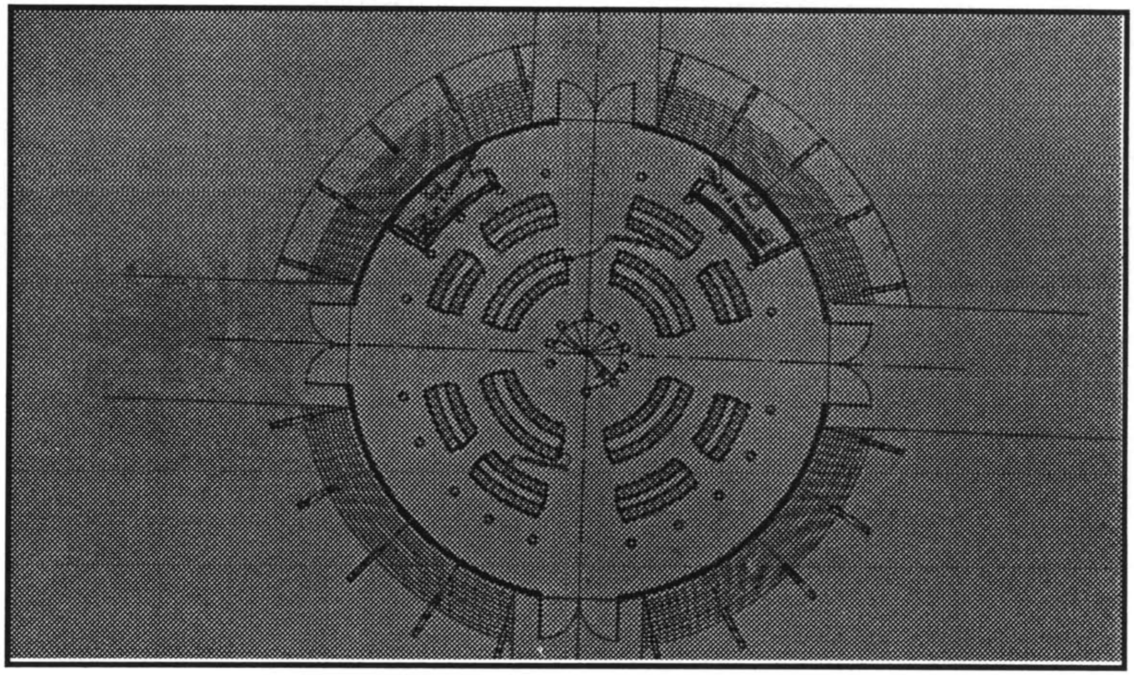
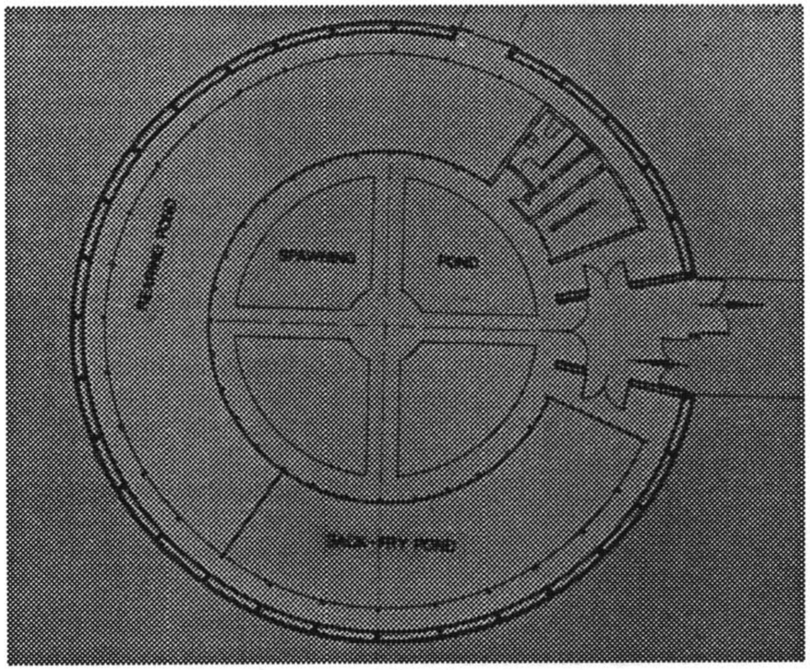


Figure 8a" : Plan of Hatchery

Once the eggs are hatched they will be placed in the rearing pond where they remain until they are grown into fingerlings (fig. 8c' & 8c"). At the fingerling stage the young fish are then placed into the growing pond where they remain until they become mature fish. At the mature stage the majority of the fish are then placed in the outdoor ponds for a short period until harvest time. The remainder, known as broodfish, will be placed in the spawning pond for spawning. It is at this stage that the growth cycle begins again. From this point on, the hatchery will be provided with fresh eggs from broodfish grown within this aquaculture facility.



Figire 8b' : Plan of Indoor Fish Pond

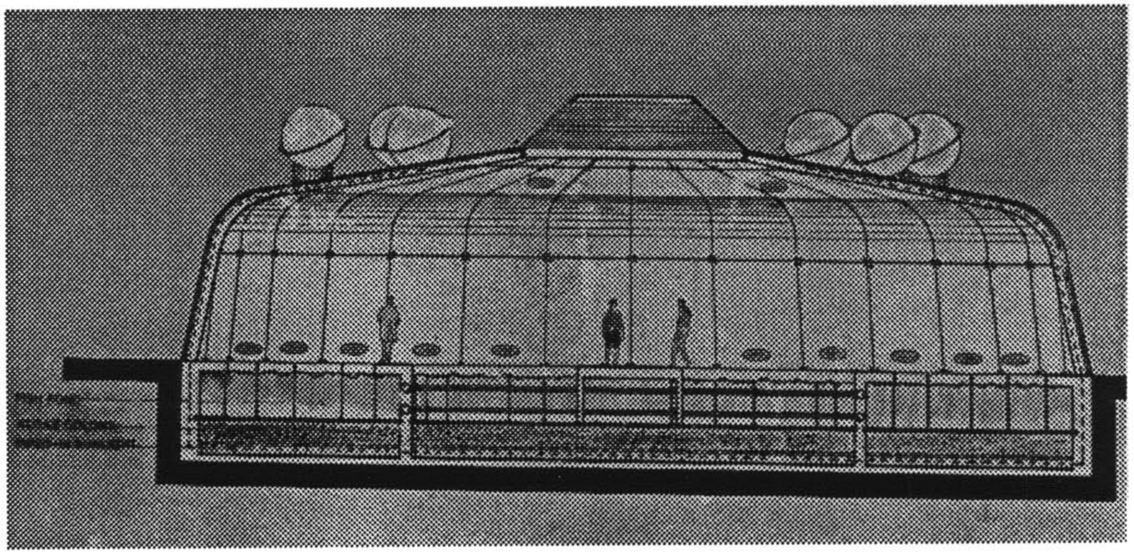


Figure 8b" : Section Through The Indoor Controlled Environment Fish Pond

In an attempt to make the aquaculture facility as energy efficient as possible, the enclosed fish ponds are designed in such a way that very little or no mechanical systems will be needed to aerate or filter the water in the fish ponds. For this design, an algae colony was placed at the bottom of each indoor fish pond to supply enough oxygen to the fish culture above (fig. 8d).

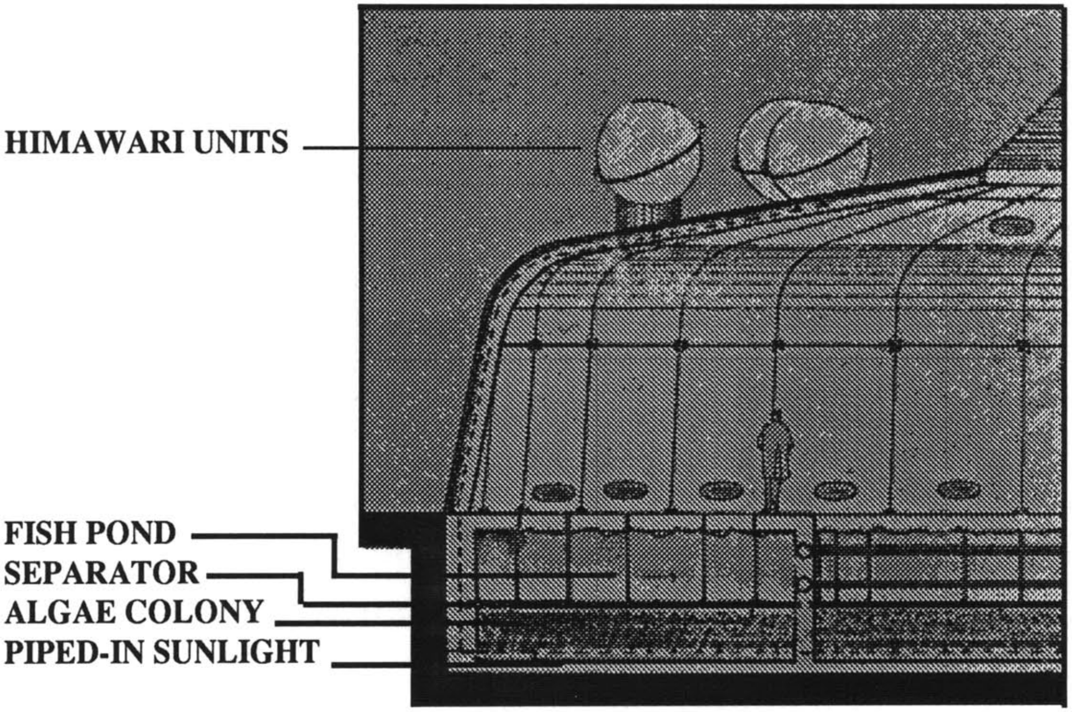


Figure 8d: Sunlight, Algae, and Fish Culture

Figure 8d shows a hierarchy of activities. First of all the Himawari units are mounted on the roof of each controlled environment fish pond. The optic fibers of these Himawari units travel from the end of the fresnel lens, through the structure of the exterior cladding, to the perimeter wall of the algae colony, and the base of the colony, just above the foundation of the structure. Above the algae colony is a wire mesh separator that separates the algae colony and fish pond.

The diagram shown in figure 8e is the lighting plan design for the algae colony. The radiating and bi-secting lines are just guide lines to orient the placement of the optical fibers. The lighting design is based on the concept of suppling daylight from all directions within the 80 ft. wide, by 2 ft. deep algae colony.

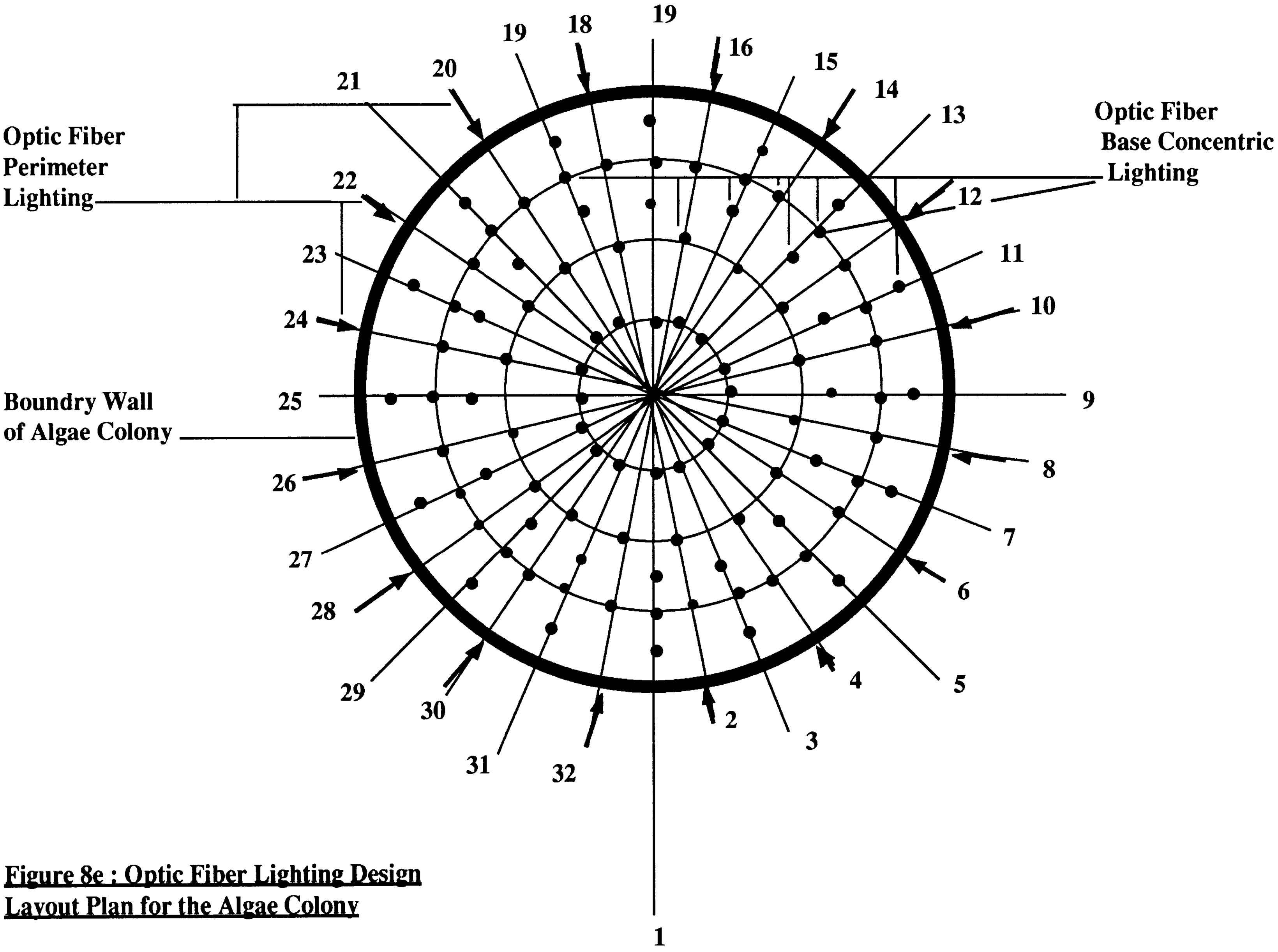


Figure 8e : Optic Fiber Lighting Design Layout Plan for the Algae Colony

The main objective of the design is to have maximum light to foster photosynthesis of the algae. The lighting plan shows a design in which optic fibers are located on ten foot intervals, radiating from the center of the circular algae colony. The trajectory of the optic fibers located beneath the algae colony is directed upwards, while the trajectory of the optic fibers located on the perimeter wall is directed into the algae colony. This design is further reinforced by the inner radiating circles which are used as guides for the strategic placement of the base optic fiber lighting, and the arrows on the outer circle, which represent perimeter optic fiber lighting. The outer circle is the true boundary of the algae colony. The lighting also shows a concentration of the optic fibers located on the 20 ft. wide inner circle. This portion of the lighting design serves a dual purpose. First of all, the optic fibers perform a common function of illuminating the algae colony. Secondly, the last paragraph of this chapter discusses in great depth, how the manipulation of light can affect the reproductive system of aquatic life. For this reason these concentrated optic fibers along the inner-most circle, are strategically located so that the concentrated light intensity will not only illuminate the algae colony directly above, but also penetrate the layer of algae to the spawning pond directly above.

The optic fiber lighting design is set-up in such a manner that bundles of optic fibers are placed along each concentric circle. These bundles of optic fibers are either placed at five or ten foot intervals to try and secure an even distribution of light at the out-put end of the optic fibers. Each bundle is made-up of seven optic fibers. Each 7-fiber bundle will supply a light intensity of approximately 844 foot candles, 1' - 8" away from the out-put end of the light conducting optic fibers. From the research conducted on the growth of macro-algae, it was discovered that a light intensity of approximately 844 f.c., within the light spectrums discussed in chapter 5, will be sufficient for photosynthisic and optimum growth.

In this design the Himawari unit being used is called the XF-110/90. This is a smaller unit than the one proposed for piping sunlight to the seedling room within the plant growth environment. This unit has 90 optic fibers. Now, since seven sets of sixteen bundles of optic fibers are placed along each concentric circle, it implies that 112 bundles will be needed to pipe sunlight to each algae colony. Hence, the total number of optic fibers needed will be 784. Consequently, a total of 8.7 Himawari units will be needed to supply photosynthetic active radiation to each algae colony . So, if the diameter of each XF-110/90 Himawari is 3.8 ft, and the roof surface area of each controlled environment fish pond is approximately 5024 sq. ft., it implies that the 8.7 Himawari units can be comfortably mounted on the roof of each pond.

Like other living beings, fish must receive an adquate supply of oxygen in their tissues, so that oxidation can occur. However, unlike other living beings which can almost always find themselves in a virtual ocean of oxygen, fish often find themselves in water with very low levels of oxygen. Both overfeeding and the uncontrolled growth of aquatic plants can contribute to an increase in the amount of decaying materials at the bottom of fish ponds. these decaying materials have very high oxygen demands and result in lowering the water level of oxygen. To alleviate this problem the waste from the fish and other decaying materials at the bottom of the fish pond will be used as feedstock for the algae colony (fig. 8f). The feedstock will enter the algae colony via a wire mesh that separates the fish and algae colony . The algae colony beneath the fish pond, will then receive sunlight from the Himawari System, via optic fiber cables. As a result, the algae will produce oxygen for the fish above.

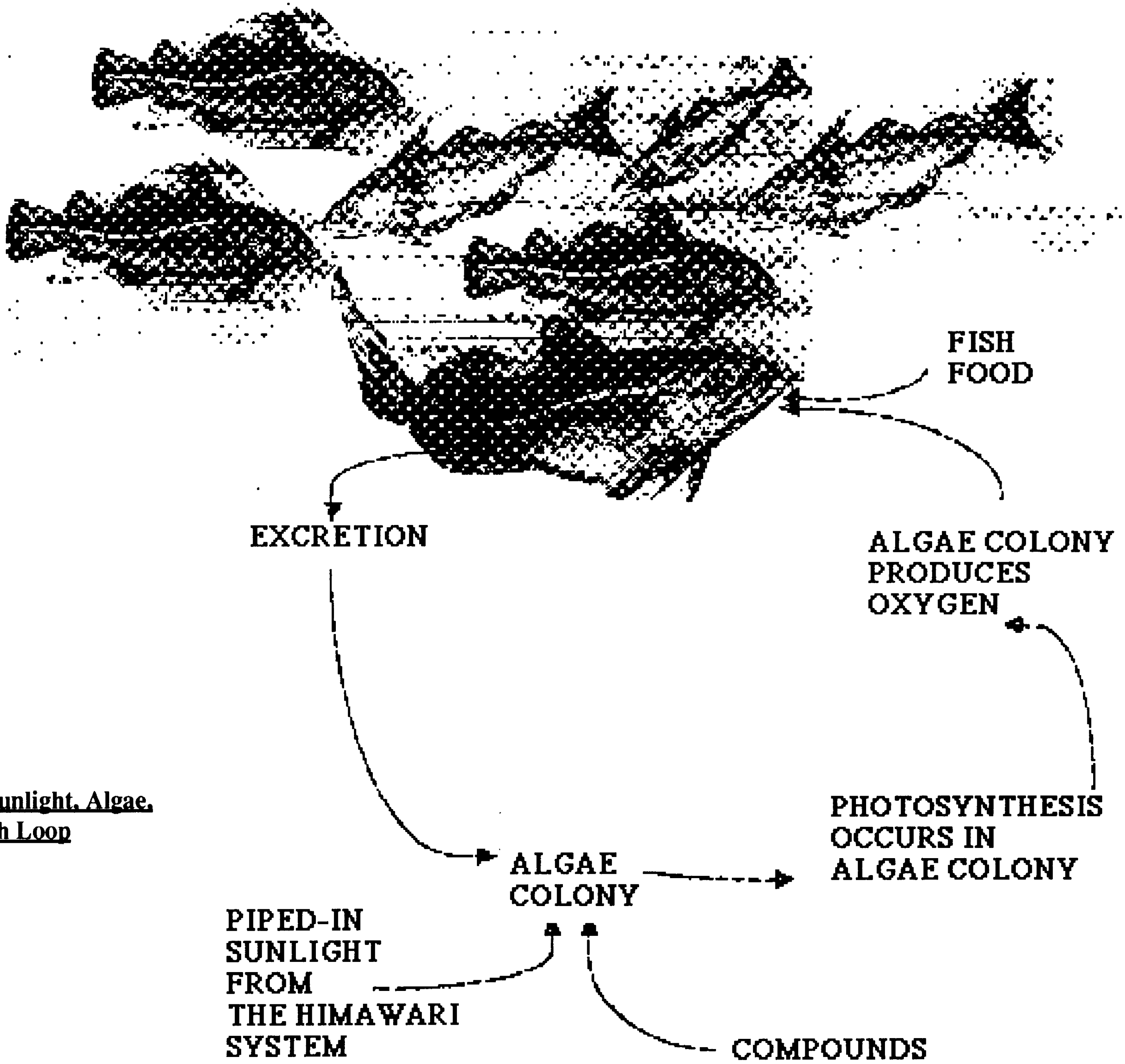


Figure 8f :The Sunlight, Algae, Oxygen, and Fish Loop

In addition, the algae colony will stabilize the fish environments, improve the water quality, and assist in keeping the pH of the system within the required range. The algae colony will utilize compounds such as nitrites, nitrates, Co2, and ammonia for assimilation and growth, and thus aid in keeping these compounds within their acceptable levels.

Light can also act through the nervous system and affect many phases of fish metabolism.[25] Changes in the duration of light can be sensed by the brain of fish, which in turn stimulates the pituitary glands which regulates important body functions such as growth and reproductive systems. Some researchers have reported that spawning for fish could be greatly advanced by first increasing and then later decreasing the light duration of the natural photoperiod change. In the natural environment it is very difficult for fish to have the above reactions to photoperiod. However, within this aquatic controlled environment the changes in light duration and intensity will be easily accomplished through a combination of piped sunlight and artificial lighting. What is most interesting here is that both sunlight and artificial light will be piped to the inner-most array of concentrated optic fiber lighting beneath the algae colony. The intensity of this optic fiber lighting will have the abality to penireate the algae colony and affect the reproductive activities within the spawning pond directly above. This technology allows a farmer to have total control over the growth and reproductive stages of the aquatic's life cycle.

CHAPTER 9 :

FOOD PRODUCTION FACILITIES ON LAND & AT SEA

The entire premise of this thesis was based on the analyses of the flow diagram of food production in the Caribbean, shown in chapter 1, figure1a. The casual loop diagram presented the scenario of an expanding population, and showed what is, and would be the impact of an expanding population on the food production industry. The casual loop diagram then suggested ways to improve food production through crop production in multi-story controlled environments, and through an improved and much more developed aquaculture industry.

This thesis has presented every fractional component fo the suggestions made in figure 1a., of chapter 1. The purpose of this thesis was to present a very passive oriented design that used traditional forms of energy very minimally. The very essence of this presentation was to use daylight to provide photosynthetic active radiation to all plants within the plant environment, and algae within the algae colony of the aquatic facility. To accomplish these goals, several techniques such as daylight reflected off light shelves and white quartz gravel ground, were analyzed and presented. In addition, daylight is also being piped via optic fibers from the Himawari system to the seedling crops and the algae colonies.

After careful analysis of several forms of energy, it was discovered that wind energy would be most appropriate for the climatic conditions of Trinidad.

Wind studies presented in this thesis have indicated that available wind on the proposed site which is located on the north east coast of the island, would be quite sufficient to provide power for the mechanical system of this facility.

This thesis has taken all the above analyses which shows all the present problems of food production in the region, and presented a design solution that will vastly improve both the aquaculture and crop production industry.

The series of seven figures that follows attempts to show this design proposal in its rightful context. The first of this series, figure 9a. represents the aerial view of the farming complex. This figure shows the relationship of the building to each other; the relationship of the buildings to white quartz gravel ground; the relationship of the buildings to the landscaping on the site; the relationship of the buildings to pedestrian and vehicular paths. Figure 9a. also clearly identifies the location of the wind farm that is strategically placed to receive the strong and consistent north-east winds.

Figure 9b. is a magnification of a portion of figure 9a. that shows the detailed desidn of the pedestrian path. First of all, a concious effort was made not to adversely alter the pattern of the white quartz gravel, nor its reflectance. Consequently, it was important to maintain the light reflectance of the pedestrian path just below the 85% reflectance of the white quartz gravel ground. In addition, the pedestrian path was designed within the grid of the white quartz gravel ground.

Figures 9c to 9f tells a very explicit and contexual story of how this proposed controlled environment food production facility has been very precicely designed.

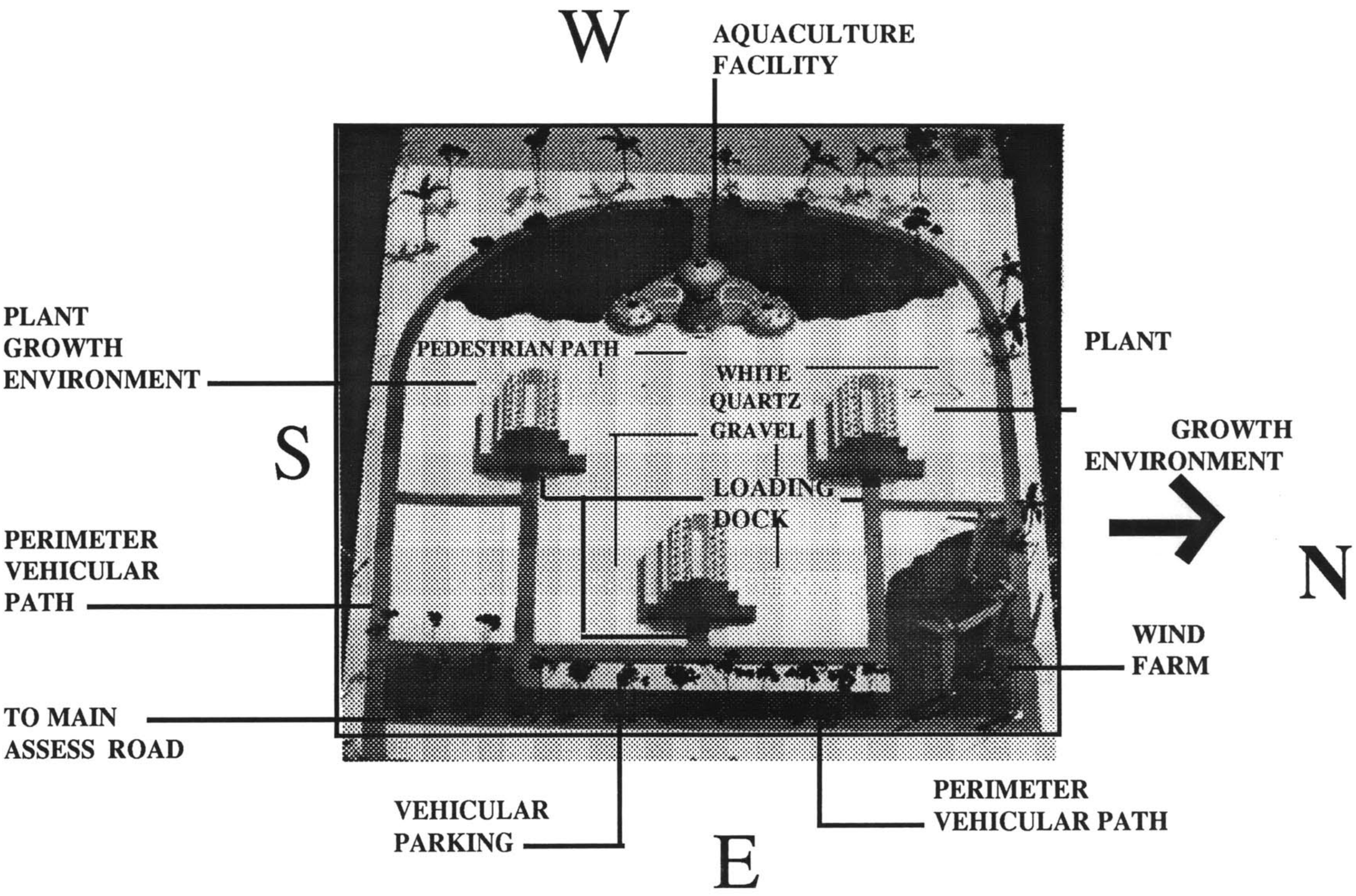


Figure 9a : Aerial View of the Proposed Design

"it was important to maintain the light reflectance of the pedestrian path, just below the 85% reflecrance of the white quartz gravel ground..."

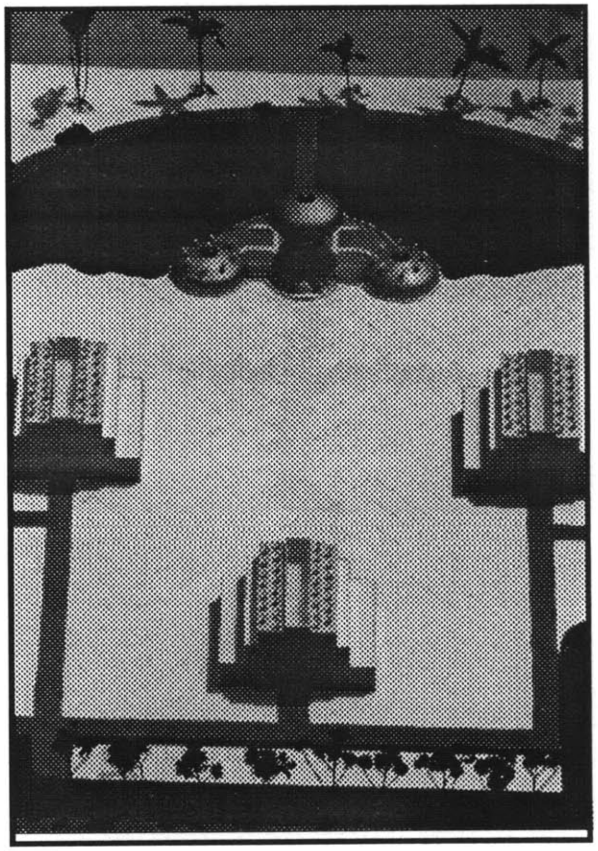


Figure 9b : Pedestrian Path Design

"the sea is located to the North of the site... the wind farm is fully accessably to the very strong and consistent North-east winds..."

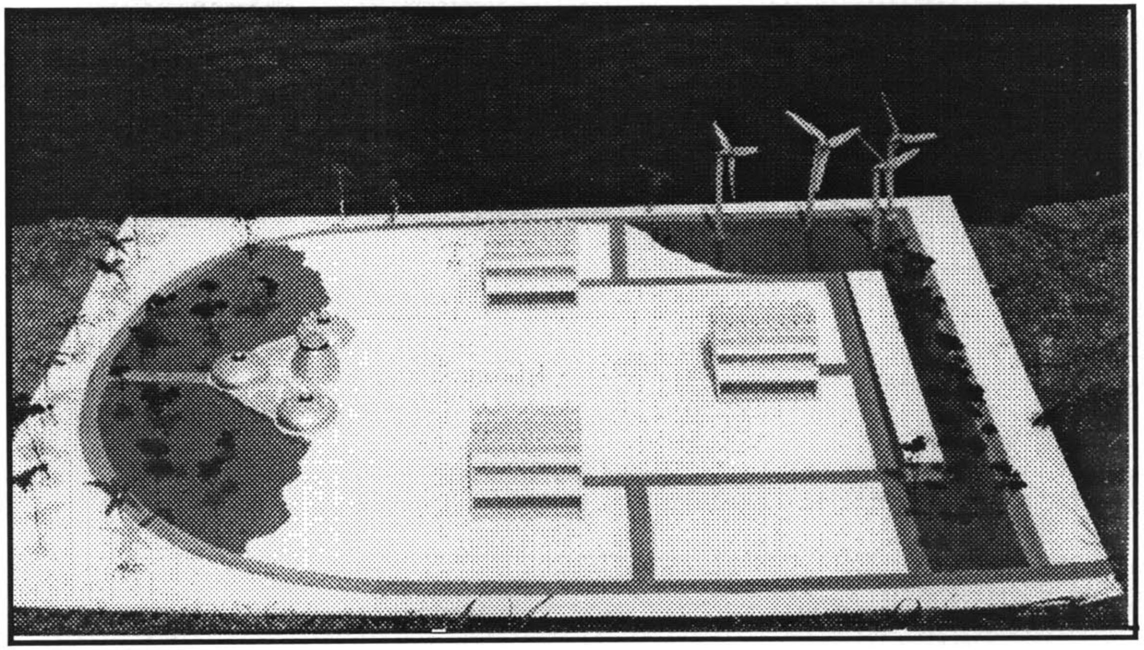


Figure 9c :

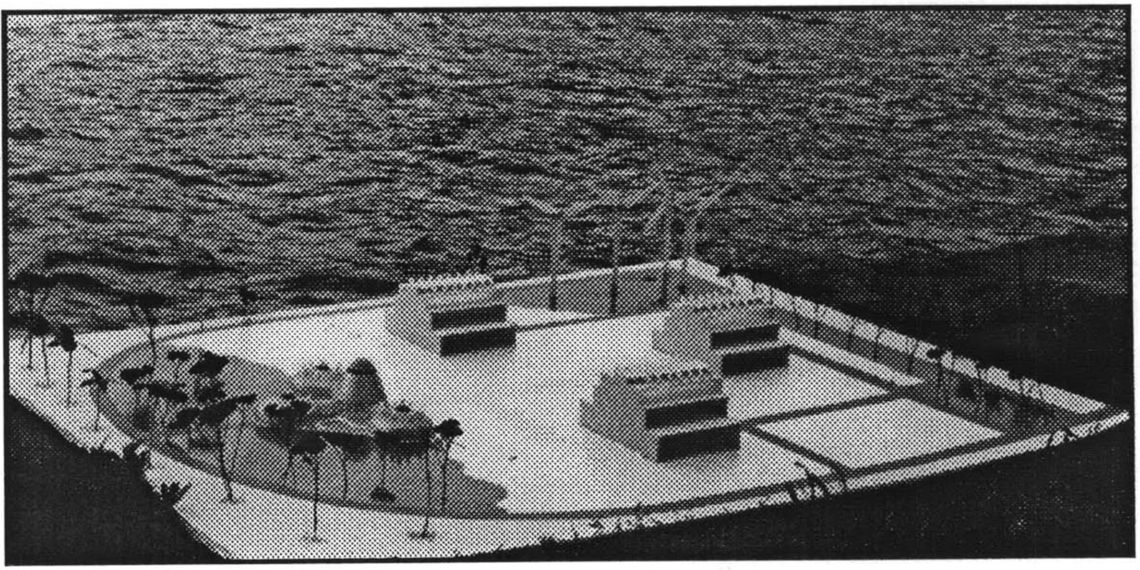


Figure 9d :

Figure 9e :

Figure 9f :

Figure 9g :

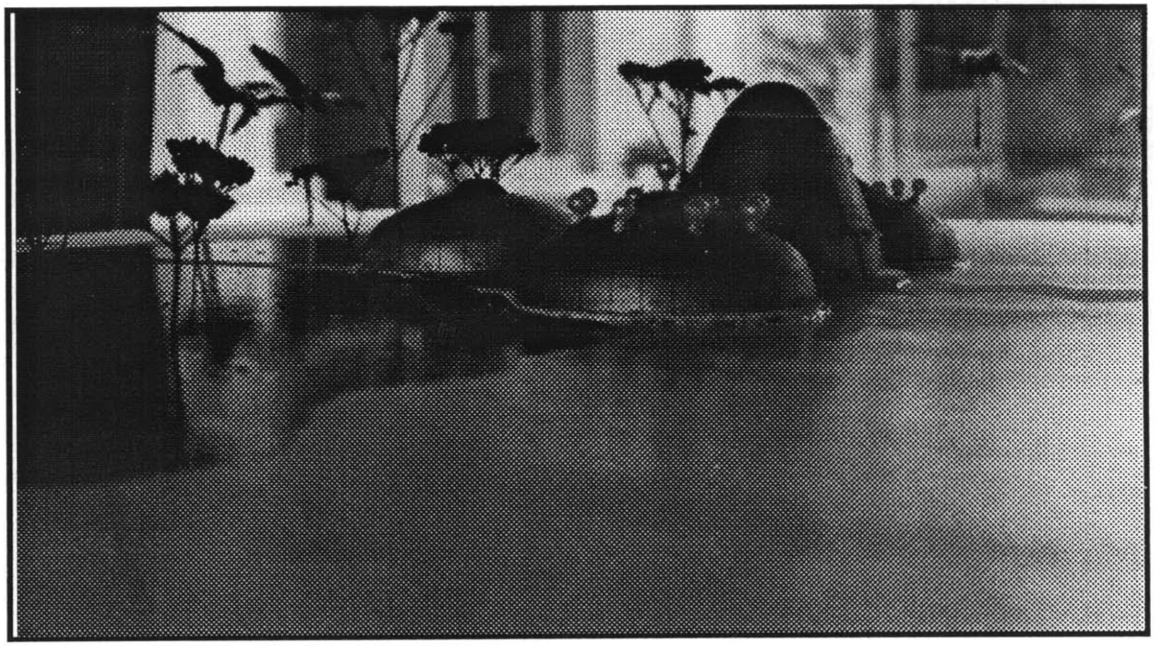


Figure 9h :

Another very important element implied in the casual loop diagram of figure 1a., is the fact that over an extended period of time, the already overpopulated islands will eventually suffer the consequences of zero available land for food production. Should this scenario ever happen, the leaders of those nations will have to depend on additional foreign assistance. However, because of the present gloomy atmosphere of Third World debt, this option may be fruitless. One option is to explore the sea.

This thesis presents an additional design of a food production facility in a controlled environment. The design presented is one in which a Controlled Environment Food Production Facility floats above the sea. The main assumption taken here is that no more land if available for food production, and the dependance on foreign food assistance has been exhausted. As a result the only alternative is to take advantage of the richness of the sea.

Figure 9i. shows the design of this proposed food production facility elevated above the sea, and supported by vertical shafts that are secured to the bottom of the ocean. This is a spin-off design of the one presented in figures 9a to 9g. However, because of the complex nature of building at sea when compared to construction on land, the entire facility is much more compact. In addition, the form of the buildings are designed to be easily assembled. Once again, the optic fiber Himawari system is proposed to supply the crops with the necessary photosynthetic active radiation. The Aquaculture facility is designed in such a manner that one of its major function is to replenish the fish population of the sea. As a result, once the mature eggs enter the sack fry pond within the controlled environment they remain there until they are healthy enough to enter the sea.

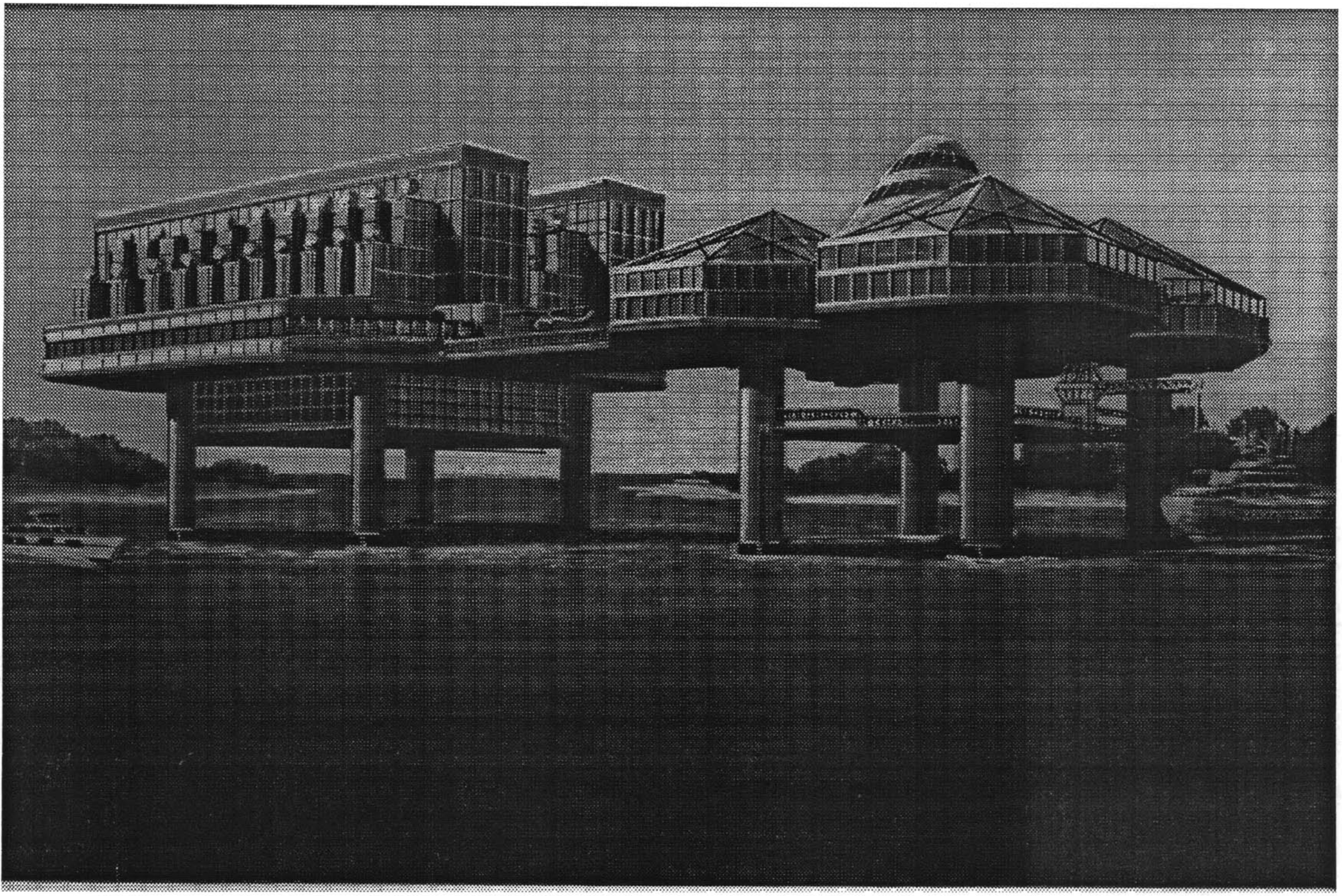


Figure 9i: Food Production Facility At Sea

At that point a catch is released and these sack fry enter the ocean via the vertical hallow shafts beneath each fish pond. In this design the quality and quantity of lighting is not only important to the plant environment, but also to the aquaculture facility where Lo-E glazing at the roof of each fish pond allows daylight to enter. The shafts that support the structure are also used as vertical circulation. As shown in figure 9i., the success of this facility is solely dependent on sea and air transportation. A crane on the lower platform, under the aquaculture facility is shown loading on the ships that transports food products to the land, and materials and supplies back to the facility at sea.

One may view the two proposed facility as being futuristic. However, the supporting research presented in this thesis, along with thousands of published literature on the subject of food production, have all agreed that something must be done to improve world food production, especially in third world countries. This thesis has attempted to present two design solutions that can assist in the improvement of food production in the Caribbean and other Equatorial Climates.

APPENDIX 1 :

DAYLIGHT TRANSMITTED THROUGH THE Lo_E GLAZING

DAYLIGHT FACTOR : 5FT. FROM WINDOW

GROUND FLOOR

CEILING:
90% OF 5000 SQ. FT. = 4500 SQ. FT.
FLOOR :
50% OF 5000 SQ. FT. = 2500 SQ. FT.
VERTICAL WALL :
90% OF 5000 SQ. FT. = 4500 SQ. FT.
GLASS WALL :
15% OF 2500 SQ. FT. = 375 SQ. FT.
TOTAL SurfaceAREA = Aceiling+Afloor+Awall+Aglass wall
= 5000+5000+5000+2500 SQ. FT.
= 17500 SQ. FT.
AVERAGE REFLECTANCE FACTOR = 11875 SQ. FT./17500 SQ. FT.
= .68 OR 68%

Aimaginary window 2500 SQ. FT.
.... = ...
TOTAL SURFACE AREA 17500 SQ. FT.
= 0.14
SO, INTERNAL REFLECTANCE COMPONENT OF DAYLIGHT FACTOR
= 10%
SKY COMPONENT = 27.7%
EXTERNAL REFLECTED COMP'T. = 10% OF SKY COMPONENT
= 2.77%

DAYLIGHT FACTOR = 40.47%
$DF*DF_{\text{white quartz gravel}}/DF_{\text{grass}}$ (Final Daylight Factor) = 40.47*1.23
= 49.8%

Hor. Irrad. Gr fl 5' fm. wind.

			Average Outdoor Horizontal Irradince (Foot Candle)	Final Daylight Factor (Df*dfwqg/dfgrass) 0.498 (Foot Candle)	Transmittance Through Lo_E 0.81 (Foot Candle)
Jan. 21	Am	Pm			
	7	5	891	444	360
	8	4	3,495	1,741	1,410
	9	3	5,962	2,969	2,405
	10	2	7,846	3,907	3,165
	11	1	9,046	4,505	3,649
	12	12	9,423	4,693	3,801
Feb. 21	Am	Pm			
	7	5	1,201	598	484
	8	4	4,099	2,041	1,653
	9	3	6,749	3,361	2,722
	10	2	8,728	4,347	3,521
	11	1	9,999	4,980	4,034
	12	12	10,388	5,173	4,190
Mar. 21	Am	Pm			
	7	5	1,507	750	608
	8	4	4,520	2,251	1,823
	9	3	7,138	3,555	2,880
	10	2	9,183	4,573	3,704
	11	1	10,402	5,180	4,196
	12	12	10,761	5,359	4,341
Apr.21	Am	Pm			
	7	5	1,636	815	660
	8	4	4,385	2,184	1,769
	9	3	6,786	3,379	2,737
	10	2	8,631	4,298	3,481
	11	1	9,709	4,835	3,916
	12	12	10,057	5,008	4,056

Hor. Irrad. Gr fl 5' fm. wind.

			Average Outdoor Horizontal Irradince (Foot Candle)	Final Daylight Factor (Df*dfwqg/dfgrass) 0.498 (Foot Candle)	Transmittance Through Lo_E 0.81 (Foot Candle)
May.21	Am	Pm			
	7	5	1,606	800	648
	8	4	3,983	1,984	1,985
	9	3	5,878	2,927	2,371
	10	2	7,388	3,679	2,980
	11	1	8,577	4,271	3,460
	12	12	8,898	4,431	3,589
Jun.21	Am	Pm			
	7	5	1,338	666	539
	8	4	3,239	1,613	1,307
	9	3	4,899	2,440	1,976
	10	2	6,157	3,066	2,483
	11	1	6,960	3,466	2,807
	12	12	7,201	3,586	2,905
Jul.21	Am	Pm			
	7	5	1,443	719	582
	8	4	3,592	1,789	1,449
	9	3	5,418	2,698	2,185
	10	2	6,861	3,417	2,768
	11	1	7,715	3,842	3,112
	12	12	8,009	3,988	3,230
Aug.21	Am	Pm			
	7	5	1,434	714	578
	8	4	3,753	1,869	1,514
	9	3	5,798	2,887	2,338
	10	2	7,354	3,662	2,966
	11	1	8,300	4,133	3,348
	12	12	8,605	4,285	3,471

Hor. Irrad. Gr fl 5' fm. wind.

			Average Outdoor Horizontal Irradince (Foot Candle)	Final Daylight Factor (Df*dfwqg/dfgrass) 0.498 (Foot Candle)	Transmittance Through Lo_E 0.81 (Foot Candle)
Sep.21	Am	Pm			
	7	5	1,207	601	487
	8	4	3,563	1,774	1,437
	9	3	5,683	2,830	2,292
	10	2	7,273	3,622	2,934
	11	1	8,245	4,106	3,326
	12	12	8,539	4,252	3,444
Oct.21	Am	Pm			
	7	5	1,019	507	411
	8	4	3,388	1,687	1,366
	9	3	5,576	2,777	2,249
	10	2	7,255	3,613	2,927
	11	1	8,305	4,136	3,350
	12	12	8,634	4,300	3,483
Nov.21	Am	Pm			
	7	5	779	388	314
	8	4	3,028	1,508	1,221
	9	3	5,187	2,583	2,092
	10	2	6,806	3,389	2,745
	11	1	7,825	3,897	3,157
	12	12	8,185	4,076	3,302
Dec.21	Am	Pm			
	7	5	671	334	271
	8	4	2,869	1,429	1,157
	9	3	5,066	2,523	2,044
	10	2	6,683	3,328	2,696
	11	1	7,721	3,845	3,114
	12	12	8,087	4,027	3,262

DAYLIGHT FACTOR : 10FT. FROM WINDOW

GROUND FLOOR

CEILING:
90% OF 5000 SQ. FT. = 4500 SQ. FT.
FLOOR :
50% OF 5000 SQ. FT. = 2500 SQ. FT.
VERTICAL WALL :
90% OF 5000 SQ. FT. = 4500 SQ. FT.
GLASS WALL :
15% OF 2500 SQ. FT. = 375 SQ. FT.
TOTAL SurfaceAREA = Aceiling+Afloor+Awall+Aglass wall
= 5000+5000+5000+2500 SQ. FT.
= 17500 SQ. FT.
AVERAGE REFLECTANCE FACTOR = 11875 SQ. FT./17500 SQ. FT.
= .68 OR 68%

Aimaginary window
....
TOTAL SURFACE AREA

2500 SQ. FT.
= ....
17500 SQ. FT.
= 0.14

SO, INTERNAL REFLECTANCE COMPONENT OF DAYLIGHT FACTOR
= 10%

SKY COMPONENT = 21.34%
EXTERNAL REFLECTED COMP'T. = 10% OF SKY COMPONENT
= 2.134%

DAYLIGHT FACTOR = 33.974%
$DF*DF_{\text{white quartz gravel}}/DF_{\text{grass}}$ (Final Daylight Factor) = 33.974*1.4
= 47.56%

Hor. Irrad. Gr fl 10' fm. wind.

			Average Outdoor Horizontal Irradince (Foot Candle)	Final Daylight Factor (Df*dfwqg/dfgrass) 0.4756 (Foot Candle)	Transmittance Through Lo_E 0.81 (Foot Candle)
Jan. 21	Am	Pm			
	7	5	891	424	343
	8	4	3,495	1,662	1,346
	9	3	5,962	2,836	2,297
	10	2	7,846	3,732	3,023
	11	1	9,046	4,302	3,485
	12	12	9,423	4,482	3,630
Feb. 2	Am	Pm			
	7	5	1,201	571	463
	8	4	4,099	1,949	1,579
	9	3	6,749	3,210	2,600
	10	2	8,728	4,151	3,362
	11	1	9,999	4,756	3,852
	12	12	10,388	4,941	4,002
Mar. 2	Am	Pm			
	7	5	1,507	717	581
	8	4	4,520	2,150	1,742
	9	3	7,138	3,395	2,750
	10	2	9,183	4,367	3,537
	11	1	10,402	4,947	4,007
	12	12	10,761	5,118	4,146
Apr.21	Am	Pm			
	7	5	1,636	778	630
	8	4	4,385	2,086	1,690
	9	3	6,786	3,227	2,614
	10	2	8,631	4,105	3,325
	11	1	9,709	4,618	3,741
	12	12	10,057	4,783	3,874

Hor. Irrad. Gr fl 10' fm. wind.

			Average Outdoor Horizontal Irradince (Foot Candle)	Final Daylight Factor (Df*dfwqg/dfgrass) 0.4756 (Foot Candle)	Transmittance Through Lo_E 0.81 (Foot Candle)
May.2	Am	Pm			
	7	5	1,606	764	619
	8	4	3,983	1,894	1,895
	9	3	5,878	2,796	2,265
	10	2	7,388	3,514	2,846
	11	1	8,577	4,079	3,304
	12	12	8,898	4,232	3,428
Jun.21	Am	Pm			
	7	5	1,338	636	515
	8	4	3,239	1,540	1,247
	9	3	4,899	2,330	1,887
	10	2	6,157	2,928	2,372
	11	1	6,960	3,310	2,681
	12	12	7,201	3,425	2,774
Jul.21	Am	Pm			
	7	5	1,443	686	556
	8	4	3,592	1,708	1,383
	9	3	5,418	2,577	2,087
	10	2	6,861	3,263	2,643
	11	1	7,715	3,669	2,972
	12	12	8,009	3,809	3,085
Aug.2	Am	Pm			
	7	5	1,434	682	552
	8	4	3,753	1,785	1,446
	9	3	5,798	2,758	2,234
	10	2	7,354	3,498	2,833
	11	1	8,300	3,947	3,197
	12	12	8,605	4,093	3,315

Hor. Irrad. Gr fl 10' fm. wind.

Sep.21	Am	Pm	Average Outdoor Horizontal Irradince (Foot Candle)	Final Daylight Factor (Df*dfwqg/dfgrass) 0.4756 (Foot Candle)	Transmittance Through Lo_E 0.81 (Foot Candle)
	7	5	1,207	574	465
	8	4	3,563	1,695	1,373
	9	3	5,683	2,703	2,189
	10	2	7,273	3,459	2,802
	11	1	8,245	3,921	3,176
	12	12	8,539	4,061	3,289
Oct.21	Am	Pm			
	7	5	1,019	485	393
	8	4	3,388	1,611	1,305
	9	3	5,576	2,652	2,148
	10	2	7,255	3,450	2,795
	11	1	8,305	3,950	3,200
	12	12	8,634	4,106	3,326
Nov.2	Am	Pm			
	7	5	779	370	300
	8	4	3,028	1,440	1,166
	9	3	5,187	2,467	1,998
	10	2	6,806	3,237	2,622
	11	1	7,825	3,722	3,015
	12	12	8,185	3,893	3,153
Dec.21	Am	Pm			
	7	5	671	319	258
	8	4	2,869	1,364	1,105
	9	3	5,066	2,409	1,951
	10	2	6,683	3,178	2,574
	11	1	7,721	3,672	2,974
	12	12	8,087	3,846	3,115

DAYLIGHT FACTOR : 15FT. FROM WINDOW

GROUND FLOOR

CEILING:
90% OF 5000 SQ. FT. = 4500 SQ. FT.
FLOOR :
50% OF 5000 SQ. FT. = 2500 SQ. FT.
VERTICAL WALL :
90% OF 5000 SQ. FT. = 4500 SQ. FT.
GLASS WALL :
15% OF 2500 SQ. FT. = 375 SQ. FT.
TOTAL SurfaceAREA = Aceiling+Afloor+Awall+Aglass wall
= 5000+5000+5000+2500 SQ. FT.
= 17500 SQ. FT.
AVERAGE REFLECTANCE FACTOR = 11875 SQ. FT./17500 SQ. FT.
= .68 OR 68%

Aimaginary window 2500 SQ. FT.
.... = ...
TOTAL SURFACE AREA 17500 SQ. FT.
= 0.14
SO, INTERNAL REFLECTANCE COMPONENT OF DAYLIGHT FACTOR
= 10%

SKY COMPONENT = 15.5%
EXTERNAL REFLECTED COMP'T. = 10% OF SKY COMPONENT
= 1.55%

DAYLIGHT FACTOR = 27.55%
$DF*DF_{\text{white quartz gravel}}/DF_{\text{grass}}$ (Final Daylight Factor) = 27.55*1.5
= 41.325%

Hor. Irrad. Gr fl 15' fm. wind.

			Average Outdoor Horizontal Irradince	Final Daylight Factor (Df*dfwqg/dfgrass)	Transmittance Through Lo_E
				0.41325	0.81
Jan. 21	Am	Pm	(Foot Candle)	(Foot Candle)	(Foot Candle)
	7	5	891	368	298
	8	4	3,495	1,444	1,170
	9	3	5,962	2,464	1,996
	10	2	7,846	3,242	2,626
	11	1	9,046	3,738	3,028
	12	12	9,423	3,894	3,154
Feb. 21	Am	Pm			
	7	5	1,201	496	402
	8	4	4,099	1,694	1,372
	9	3	6,749	2,789	2,259
	10	2	8,728	3,607	2,922
	11	1	9,999	4,132	3,347
	12	12	10,388	4,293	3,477
Mar. 21	Am	Pm			
	7	5	1,507	623	505
	8	4	4,520	1,868	1,513
	9	3	7,138	2,950	2,390
	10	2	9,183	3,795	3,074
	11	1	10,402	4,299	3,482
	12	12	10,761	4,447	3,602
Apr.21	Am	Pm			
	7	5	1,636	676	548
	8	4	4,385	1,812	1,468
	9	3	6,786	2,804	2,271
	10	2	8,631	3,567	2,889
	11	1	9,709	4,012	3,250
	12	12	10,057	4,156	3,366

Hor. Irrad. Gr fl 15' fm. wind.

			Average Outdoor Horizontal Irradince (Foot Candle)	Final Daylight Factor (Df*dfwqg/dfgrass) 0.41325 (Foot Candle)	Transmittance Through Lo_E 0.81 (Foot Candle)
May.21	Am	Pm			
	7	5	1,606	664	538
	8	4	3,983	1,646	1,647
	9	3	5,878	2,429	1,967
	10	2	7,388	3,053	2,473
	11	1	8,577	3,544	2,871
	12	12	8,898	3,677	2,978
Jun.21	Am	Pm			
	7	5	1,338	553	448
	8	4	3,239	1,339	1,085
	9	3	4,899	2,025	1,640
	10	2	6,157	2,544	2,061
	11	1	6,960	2,876	2,330
	12	12	7,201	2,976	2,411
Jul.21	Am	Pm			
	7	5	1,443	596	483
	8	4	3,592	1,484	1,202
	9	3	5,418	2,239	1,814
	10	2	6,861	2,835	2,296
	11	1	7,715	3,188	2,582
	12	12	8,009	3,310	2,681
Aug.21	Am	Pm			
	7	5	1,434	593	480
	8	4	3,753	1,551	1,256
	9	3	5,798	2,396	1,941
	10	2	7,354	3,039	2,462
	11	1	8,300	3,430	2,778
	12	12	8,605	3,556	2,880

Hor. Irrad. Gr fl 15' fm. wind.

Sep.21	Am	Pm	Average Outdoor Horizontal Irradince (Foot Candle)	Final Daylight Factor (Df*dfwqg/dfgrass) 0.41325 (Foot Candle)	Transmittance Through Lo_E 0.81 (Foot Candle)
	7	5	1,207	499	404
	8	4	3,563	1,472	1,192
	9	3	5,683	2,348	1,902
	10	2	7,273	3,006	2,435
	11	1	8,245	3,407	2,760
	12	12	8,539	3,529	2,858
Oct.21	Am	Pm			
	7	5	1,019	421	341
	8	4	3,388	1,400	1,134
	9	3	5,576	2,304	1,866
	10	2	7,255	2,998	2,428
	11	1	8,305	3,432	2,780
	12	12	8,634	3,568	2,890
Nov.21	Am	Pm			
	7	5	779	322	261
	8	4	3,028	1,251	1,013
	9	3	5,187	2,144	1,737
	10	2	6,806	2,813	2,279
	11	1	7,825	3,234	2,620
	12	12	8,185	3,382	2,739
Dec.21	Am	Pm			
	7	5	671	277	224
	8	4	2,869	1,186	961
	9	3	5,066	2,094	1,696
	10	2	6,683	2,762	2,237
	11	1	7,721	3,191	2,585
	12	12	8,087	3,342	2,707

DAYLIGHT FACTOR : 20FT. FROM WINDOW

GROUND FLOOR

CEILING:
90% OF 5000 SQ. FT. = 4500 SQ. FT.
FLOOR :
50% OF 5000 SQ. FT. = 2500 SQ. FT.
VERTICAL WALL :
90% OF 5000 SQ. FT. = 4500 SQ. FT.
GLASS WALL :
15% OF 2500 SQ. FT. = 375 SQ. FT.
TOTAL SurfaceAREA = Aceiling+Afloor+Awall+Aglass wall
= 5000+5000+5000+2500 SQ. FT.
= 17500 SQ. FT.
AVERAGE REFLECTANCE FACTOR = 11875 SQ. FT./17500 SQ. FT.
= .68 OR 68%

Aimaginary window 2500 SQ. FT.
.... = ...
TOTAL SURFACE AREA 17500 SQ. FT.
= 0.14
SO, INTERNAL REFLECTANCE COMPONENT OF DAYLIGHT FACTOR
= 10%
SKY COMPONENT = 11.52%
EXTERNAL REFLECTED COMP'T. = 10% OF SKY COMPONENT
= 1.55%
DAYLIGHT FACTOR = 23.172%
$DF*DF_{\text{white quartz gravel}}/DF_{\text{grass}}$ (Final Daylight Factor) = 23.172*1.57
= 36.38%

Hor. Irrad. Gr fl 20' fm. wind.

Jan. 21 Am	Pm	Average Outdoor Horizontal Irradince (Foot Candle)	Final Daylight Factor (Df*dfwqg/dfgrass) 0.3638 (Foot Candle)	Transmittance Through Lo_E 0.81 (Foot Candle)
7	5	891	324	262
8	4	3,495	1,271	1,030
9	3	5,962	2,169	1,757
10	2	7,846	2,854	2,312
11	1	9,046	3,291	2,666
12	12	9,423	3,428	2,777
Feb. 2 Am	Pm			
7	5	1,201	437	354
8	4	4,099	1,491	1,208
9	3	6,749	2,455	1,989
10	2	8,728	3,175	2,572
11	1	9,999	3,638	2,947
12	12	10,388	3,779	3,061
Mar. 2 Am	Pm			
7	5	1,507	548	444
8	4	4,520	1,644	1,332
9	3	7,138	2,597	2,104
10	2	9,183	3,341	2,706
11	1	10,402	3,784	3,065
12	12	10,761	3,915	3,171
Apr.21 Am	Pm			
7	5	1,636	595	482
8	4	4,385	1,595	1,292
9	3	6,786	2,469	2,000
10	2	8,631	3,140	2,543
11	1	9,709	3,532	2,861
12	12	10,057	3,659	2,964

Hor. Irrad. Gr fl 20' fm. wind.

			Average Outdoor Horizontal Irradince (Foot Candle)	Final Daylight Factor (Df*dfwqg/dfgrass) 0.3638 (Foot Candle)	Transmittance Through Lo_E 0.81 (Foot Candle)
May.2	Am	Pm			
	7	5	1,606	584	473
	8	4	3,983	1,449	1,450
	9	3	5,878	2,138	1,732
	10	2	7,388	2,688	2,177
	11	1	8,577	3,120	2,527
	12	12	8,898	3,237	2,622
Jun.21	Am	Pm			
	7	5	1,338	487	394
	8	4	3,239	1,178	954
	9	3	4,899	1,782	1,443
	10	2	6,157	2,240	1,814
	11	1	6,960	2,532	2,051
	12	12	7,201	2,620	2,122
Jul.21	Am	Pm			
	7	5	1,443	525	425
	8	4	3,592	1,307	1,059
	9	3	5,418	1,971	1,597
	10	2	6,861	2,496	2,022
	11	1	7,715	2,807	2,274
	12	12	8,009	2,914	2,360
Aug.2	Am	Pm			
	7	5	1,434	522	423
	8	4	3,753	1,365	1,106
	9	3	5,798	2,109	1,708
	10	2	7,354	2,675	2,167
	11	1	8,300	3,020	2,446
	12	12	8,605	3,130	2,535

Hor. Irrad. Gr fl 20' fm. wind.

Sep.21 Am	Pm	Average Outdoor Horizontal Irradince (Foot Candle)	Final Daylight Factor (Df*dfwqg/dfgrass) 0.3638 (Foot Candle)	Transmittance Through Lo_E 0.81 (Foot Candle)
7	5	1,207	439	356
8	4	3,563	1,296	1,050
9	3	5,683	2,067	1,674
10	2	7,273	2,646	2,143
11	1	8,245	3,000	2,430
12	12	8,539	3,106	2,516
Oct.21 Am	Pm			
7	5	1,019	371	301
8	4	3,388	1,233	999
9	3	5,576	2,029	1,643
10	2	7,255	2,639	2,138
11	1	8,305	3,021	2,447
12	12	8,634	3,141	2,544
Nov.2 Am	Pm			
7	5	779	283	229
8	4	3,028	1,102	893
9	3	5,187	1,887	1,528
10	2	6,806	2,476	2,006
11	1	7,825	2,847	2,306
12	12	8,185	2,978	2,412
Dec.21 Am	Pm			
7	5	671	244	198
8	4	2,869	1,044	846
9	3	5,066	1,843	1,493
10	2	6,683	2,431	1,969
11	1	7,721	2,809	2,275
12	12	8,087	2,942	2,383

DAYLIGHT FACTOR : 25FT. FROM WINDOW

GROUND FLOOR

CEILING:
90% OF 5000 SQ. FT. = 4500 SQ. FT.
FLOOR :
50% OF 5000 SQ. FT. = 2500 SQ. FT.
VERTICAL WALL :
90% OF 5000 SQ. FT. = 4500 SQ. FT.
GLASS WALL :
15% OF 2500 SQ. FT. = 375 SQ. FT.
TOTAL SurfaceAREA = Aceiling+Afloor+Awall+Aglass wall
= 5000+5000+5000+2500 SQ. FT.
= 17500 SQ. FT.
AVERAGE REFLECTANCE FACTOR = 11875 SQ. FT./17500 SQ. FT.
= .68 OR 68%

$$\frac{\text{Aimaginary window}}{\text{TOTAL SURFACE AREA}} = \frac{2500 \text{ SQ. FT.}}{17500 \text{ SQ. FT.}}$$

= 0.14
SO, INTERNAL REFLECTANCE COMPONENT OF DAYLIGHT FACTOR
= 10%
SKY COMPONENT = 8%
EXTERNAL REFLECTED COMP'T. = 10% OF SKY COMPONENT
= 0.8%
DAYLIGHT FACTOR = 19.3%
$DF*DF_{\text{white quartz gravel}}/DF_{\text{grass}}$ (Final Daylight Factor) = 19.3*1.6
= 30.88%

Hor. Irrad. Gr fl 25' fm. wind.

Jan. 21	Am	Pm	Average Outdoor Horizontal Irradince (Foot Candle)	Final Daylight Factor (Df*dfwqg/dfgrass) 0.3088 (Foot Candle)	Transmittance Through Lo_E 0.81 (Foot Candle)
	7	5	891	275	223
	8	4	3,495	1,079	874
	9	3	5,962	1,841	1,491
	10	2	7,846	2,423	1,963
	11	1	9,046	2,793	2,262
	12	12	9,423	2,910	2,357
Feb. 2	Am	Pm			
	7	5	1,201	371	301
	8	4	4,099	1,266	1,025
	9	3	6,749	2,084	1,688
	10	2	8,728	2,695	2,183
	11	1	9,999	3,088	2,501
	12	12	10,388	3,208	2,598
Mar. 2	Am	Pm			
	7	5	1,507	465	377
	8	4	4,520	1,396	1,131
	9	3	7,138	2,204	1,785
	10	2	9,183	2,836	2,297
	11	1	10,402	3,212	2,602
	12	12	10,761	3,323	2,692
Apr.21	Am	Pm			
	7	5	1,636	505	409
	8	4	4,385	1,354	1,097
	9	3	6,786	2,096	1,698
	10	2	8,631	2,665	2,159
	11	1	9,709	2,998	2,428
	12	12	10,057	3,106	2,516

Hor. Irrad. Gr fl 25' fm. wind.

May.2	Am	Pm	Average Outdoor Horizontal Irradince (Foot Candle)	Final Daylight Factor (Df*dfwqg/dfgrass) 0.3088 (Foot Candle)	Transmittance Through Lo_E 0.81 (Foot Candle)
	7	5	1,606	496	402
	8	4	3,983	1,230	1,231
	9	3	5,878	1,815	1,470
	10	2	7,388	2,281	1,848
	11	1	8,577	2,649	2,146
	12	12	8,898	2,748	2,226
Jun.21	Am	Pm			
	7	5	1,338	413	335
	8	4	3,239	1,000	810
	9	3	4,899	1,513	1,226
	10	2	6,157	1,901	1,540
	11	1	6,960	2,149	1,741
	12	12	7,201	2,224	1,801
Jul.21	Am	Pm			
	7	5	1,443	446	361
	8	4	3,592	1,109	898
	9	3	5,418	1,673	1,355
	10	2	6,861	2,119	1,716
	11	1	7,715	2,382	1,929
	12	12	8,009	2,473	2,003
Aug.2	Am	Pm			
	7	5	1,434	443	359
	8	4	3,753	1,159	939
	9	3	5,798	1,790	1,450
	10	2	7,354	2,271	1,840
	11	1	8,300	2,563	2,076
	12	12	8,605	2,657	2,152

Hor. Irrad. Gr fl 25' fm. wind.

			Average Outdoor Horizontal Irradince	Final Daylight Factor (Df*dfwqg/dfgrass) 0.3088	Transmittance Through Lo_E 0.81
Sep.21	Am	Pm	(Foot Candle)	(Foot Candle)	(Foot Candle)
	7	5	1,207	373	302
	8	4	3,563	1,100	891
	9	3	5,683	1,755	1,422
	10	2	7,273	2,246	1,819
	11	1	8,245	2,546	2,062
	12	12	8,539	2,637	2,136
Oct.21	Am	Pm			
	7	5	1,019	315	255
	8	4	3,388	1,046	847
	9	3	5,576	1,722	1,395
	10	2	7,255	2,240	1,814
	11	1	8,305	2,565	2,078
	12	12	8,634	2,666	2,159
Nov.2	Am	Pm			
	7	5	779	241	195
	8	4	3,028	935	757
	9	3	5,187	1,602	1,298
	10	2	6,806	2,102	1,703
	11	1	7,825	2,416	1,957
	12	12	8,185	2,528	2,048
Dec.21	Am	Pm			
	7	5	671	207	168
	8	4	2,869	886	718
	9	3	5,066	1,564	1,267
	10	2	6,683	2,064	1,672
	11	1	7,721	2,384	1,931
	12	12	8,087	2,497	2,023

DAYLIGHT FACTOR : 30FT. FROM WINDOW

GROUND FLOOR

CEILING:
90% OF 5000 SQ. FT. = 4500 SQ. FT.
FLOOR :
50% OF 5000 SQ. FT. = 2500 SQ. FT.
VERTICAL WALL :
90% OF 5000 SQ. FT. = 4500 SQ. FT.
GLASS WALL :
15% OF 2500 SQ. FT. = 375 SQ. FT.
TOTAL SurfaceAREA = Aceiling+Afloor+Awall+Aglass wall
= 5000+5000+5000+2500 SQ. FT.
= 17500 SQ. FT.
AVERAGE REFLECTANCE FACTOR = 11875 SQ. FT./17500 SQ. FT.
= .68 OR 68%

$$\frac{A_{imaginary\ window}}{\text{TOTAL SURFACE AREA}} = \frac{2500\ \text{SQ. FT.}}{17500\ \text{SQ. FT.}}$$

= 0.14

SO, INTERNAL REFLECTANCE COMPONENT OF DAYLIGHT FACTOR
= 10%

SKY COMPONENT = 5.85%
EXTERNAL REFLECTED COMP'T. = 10% OF SKY COMPONENT
= 0.585%

DAYLIGHT FACTOR = 16.4%
$DF*DF_{\text{white quartz gravel}}/DF_{\text{grass}}$ (Final Daylight Factor) = 16.4*1.6
= 26.24%

Hor. Irrad. Gr fl 30' fm. wind.

Jan. 21 Am	Pm	Average Outdoor Horizontal Irradince (Foot Candle)	Final Daylight Factor (Df*dfwqg/dfgrass) 0.2624 (Foot Candle)	Transmittance Through Lo_E 0.81 (Foot Candle)
7	5	891	234	190
8	4	3,495	917	743
9	3	5,962	1,564	1,267
10	2	7,846	2,059	1,668
11	1	9,046	2,374	1,923
12	12	9,423	2,473	2,003
Feb. 2 Am	Pm			
7	5	1,201	315	255
8	4	4,099	1,076	872
9	3	6,749	1,771	1,435
10	2	8,728	2,290	1,855
11	1	9,999	2,624	2,125
12	12	10,388	2,726	2,208
Mar. 2 Am	Pm			
7	5	1,507	395	320
8	4	4,520	1,186	961
9	3	7,138	1,873	1,517
10	2	9,183	2,410	1,952
11	1	10,402	2,729	2,210
12	12	10,761	2,824	2,287
Apr.21 Am	Pm			
7	5	1,636	429	347
8	4	4,385	1,151	932
9	3	6,786	1,781	1,443
10	2	8,631	2,265	1,835
11	1	9,709	2,548	2,064
12	12	10,057	2,639	2,138

Hor. Irrad. Gr fl 30' fm. wind.

May.2	Am	Pm	Average Outdoor Horizontal Irradince (Foot Candle)	Final Daylight Factor (Df*dfwqg/dfgrass) 0.2624 (Foot Candle)	Transmittance Through Lo_E 0.81 (Foot Candle)
	7	5	1,606	421	341
	8	4	3,983	1,045	1,046
	9	3	5,878	1,542	1,249
	10	2	7,388	1,939	1,571
	11	1	8,577	2,251	1,823
	12	12	8,898	2,335	1,891
Jun.21	Am	Pm			
	7	5	1,338	351	284
	8	4	3,239	850	689
	9	3	4,899	1,285	1,041
	10	2	6,157	1,616	1,309
	11	1	6,960	1,826	1,479
	12	12	7,201	1,890	1,531
Jul.21	Am	Pm			
	7	5	1,443	379	307
	8	4	3,592	943	764
	9	3	5,418	1,422	1,152
	10	2	6,861	1,800	1,458
	11	1	7,715	2,024	1,639
	12	12	8,009	2,102	1,703
Aug.2	Am	Pm			
	7	5	1,434	376	305
	8	4	3,753	985	798
	9	3	5,798	1,521	1,232
	10	2	7,354	1,930	1,563
	11	1	8,300	2,178	1,764
	12	12	8,605	2,258	1,829

Hor. Irrad. Gr fl 30' fm. wind.

	Am	Pm	Average Outdoor Horizontal Irradince (Foot Candle)	Final Daylight Factor (Df*dfwqg/dfgrass) 0.2624 (Foot Candle)	Transmittance Through Lo_E 0.81 (Foot Candle)
Sep.21	Am	Pm			
	7	5	1,207	317	257
	8	4	3,563	935	757
	9	3	5,683	1,491	1,208
	10	2	7,273	1,908	1,545
	11	1	8,245	2,163	1,752
	12	12	8,539	2,241	1,815
Oct.21	Am	Pm			
	7	5	1,019	267	216
	8	4	3,388	889	720
	9	3	5,576	1,463	1,185
	10	2	7,255	1,904	1,542
	11	1	8,305	2,179	1,765
	12	12	8,634	2,266	1,835
Nov.2	Am	Pm			
	7	5	779	204	165
	8	4	3,028	795	644
	9	3	5,187	1,361	1,102
	10	2	6,806	1,786	1,447
	11	1	7,825	2,053	1,663
	12	12	8,185	2,148	1,740
Dec.21	Am	Pm			
	7	5	671	176	143
	8	4	2,869	753	610
	9	3	5,066	1,329	1,076
	10	2	6,683	1,754	1,421
	11	1	7,721	2,026	1,641
	12	12	8,087	2,122	1,719

DAYLIGHT FACTOR : 35FT. FROM WINDOW

GROUND FLOOR

CEILING:
90% OF 5000 SQ. FT. = 4500 SQ. FT.
FLOOR :
50% OF 5000 SQ. FT. = 2500 SQ. FT.
VERTICAL WALL :
90% OF 5000 SQ. FT. = 4500 SQ. FT.
GLASS WALL :
15% OF 2500 SQ. FT. = 375 SQ. FT.
TOTAL SurfaceAREA = Aceiling+Afloor+Awall+Aglass wall
= 5000+5000+5000+2500 SQ. FT.
= 17500 SQ. FT.
AVERAGE REFLECTANCE FACTOR = 11875 SQ. FT./17500 SQ. FT.
= .68 OR 68%

Aimaginary window 2500 SQ. FT.
.... = ...
TOTAL SURFACE AREA 17500 SQ. FT.
= 0.14
SO, INTERNAL REFLECTANCE COMPONENT OF DAYLIGHT FACTOR
= 10%
SKY COMPONENT = 4.4%
EXTERNAL REFLECTED COMP'T. = 10% OF SKY COMPONENT
= 0.44%
DAYLIGHT FACTOR = 14.84%
$DF*DF_{\text{white quartz gravel}}/DF_{\text{grass}}$ (Final Daylight Factor) = 14.84*1.65
= 24.484%

Hor. Irrad. Gr fl 35' fm. wind.

			Average Outdoor Horizontal Irradince	Final Daylight Factor (Df*dfwqg/dfgrass)	Transmittance Through Lo_E
				0.24484	0.81
Jan. 21	Am	Pm	(Foot Candle)	(Foot Candle)	(Foot Candle)
	7	5	891	218	177
	8	4	3,495	856	693
	9	3	5,962	1,460	1,183
	10	2	7,846	1,921	1,556
	11	1	9,046	2,215	1,794
	12	12	9,423	2,307	1,869
Feb. 21	Am	Pm			
	7	5	1,201	294	238
	8	4	4,099	1,004	813
	9	3	6,749	1,652	1,338
	10	2	8,728	2,137	1,731
	11	1	9,999	2,448	1,983
	12	12	10,388	2,543	2,060
Mar. 21	Am	Pm			
	7	5	1,507	369	299
	8	4	4,520	1,107	897
	9	3	7,138	1,748	1,416
	10	2	9,183	2,248	1,821
	11	1	10,402	2,547	2,063
	12	12	10,761	2,635	2,134
Apr.21	Am	Pm			
	7	5	1,636	401	325
	8	4	4,385	1,074	870
	9	3	6,786	1,661	1,345
	10	2	8,631	2,113	1,712
	11	1	9,709	2,377	1,925
	12	12	10,057	2,462	1,994

Hor. Irrad. Gr fl 35' fm. wind.

May.21	Am	Pm	Average Outdoor Horizontal Irradince (Foot Candle)	Final Daylight Factor (Df*dfwqg/dfgrass) 0.4484 (Foot Candle)	Transmittance Through Lo_E 0.81 (Foot Candle)
	7	5	1,606	393	318
	8	4	3,983	975	976
	9	3	5,878	1,439	1,166
	10	2	7,388	1,809	1,465
	11	1	8,577	2,100	1,701
	12	12	8,898	2,179	1,765
Jun.21	Am	Pm			
	7	5	1,338	328	266
	8	4	3,239	793	642
	9	3	4,899	1,199	971
	10	2	6,157	1,507	1,221
	11	1	6,960	1,704	1,380
	12	12	7,201	1,763	1,428
Jul.21	Am	Pm			
	7	5	1,443	353	286
	8	4	3,592	879	712
	9	3	5,418	1,327	1,075
	10	2	6,861	1,680	1,361
	11	1	7,715	1,889	1,530
	12	12	8,009	1,961	1,588
Aug.21	Am	Pm			
	7	5	1,434	351	284
	8	4	3,753	919	744
	9	3	5,798	1,420	1,150
	10	2	7,354	1,801	1,459
	11	1	8,300	2,032	1,646
	12	12	8,605	2,107	1,707

Hor. Irrad. Gr fl 35' fm. wind.

	Am	Pm	Average Outdoor Horizontal Irradince (Foot Candle)	Final Daylight Factor (Df*dfwqg/dfgrass) 0.4484 (Foot Candle)	Transmittance Through Lo_E 0.81 (Foot Candle)
Sep.21	Am	Pm			
	7	5	1,207	296	240
	8	4	3,563	872	706
	9	3	5,683	1,391	1,127
	10	2	7,273	1,781	1,443
	11	1	8,245	2,019	1,635
	12	12	8,539	2,091	1,694
Oct.21	Am	Pm			
	7	5	1,019	249	202
	8	4	3,388	830	672
	9	3	5,576	1,365	1,106
	10	2	7,255	1,776	1,439
	11	1	8,305	2,033	1,647
	12	12	8,634	2,114	1,712
Nov.21	Am	Pm			
	7	5	779	191	155
	8	4	3,028	741	600
	9	3	5,187	1,270	1,029
	10	2	6,806	1,666	1,349
	11	1	7,825	1,916	1,552
	12	12	8,185	2,004	1,623
Dec.21	Am	Pm			
	7	5	671	164	133
	8	4	2,869	702	569
	9	3	5,066	1,240	1,004
	10	2	6,683	1,636	1,325
	11	1	7,721	1,890	1,531
	12	12	8,087	1,980	1,604

DAYLIGHT FACTOR : 40FT. FROM WINDOW

GROUND FLOOR

CEILING:

90% OF 5000 SQ. FT. = 4500 SQ. FT.

FLOOR :

50% OF 5000 SQ. FT. = 2500 SQ. FT.

VERTICAL WALL :

90% OF 5000 SQ. FT. = 4500 SQ. FT.

GLASS WALL :

15% OF 2500 SQ. FT. = 375 SQ. FT.

TOTAL SurfaceAREA = Aceiling+Afloor+Awall+Aglass wall
= 5000+5000+5000+2500 SQ. FT.
= 17500 SQ. FT.

AVERAGE REFLECTANCE FACTOR = 11875 SQ. FT./17500 SQ. FT.
= .68 OR 68%

$$\frac{\text{Aimaginary window}}{\text{TOTAL SURFACE AREA}} = \frac{\text{2500 SQ. FT.}}{\text{17500 SQ. FT.}}$$

= 0.14

SO, INTERNAL REFLECTANCE COMPONENT OF DAYLIGHT FACTOR
= 10%

SKY COMPONENT = 3.5%

EXTERNAL REFLECTED COMP'T. = 10% OF SKY COMPONENT
= 0.35%

DAYLIGHT FACTOR = 13.85%

$DF*DF_{\text{white quartz gravel}}/DF_{\text{grass}}$ (Final Daylight Factor) = 13.85*1.5
= 20.775%

Hor. Irrad. Gr fl 40' fm. wind.

			Average Outdoor Horizontal Irradince (Foot Candle)	Final Daylight Factor (Df*dfwqg/dfgrass) 0.20775 (Foot Candle)	ittance Through Lo_E 0.81 (Foot Candle)
Jan. 21	Am	Pm			
	7	5	891	185	150
	8	4	3,495	726	588
	9	3	5,962	1,239	1,004
	10	2	7,846	1,630	1,320
	11	1	9,046	1,879	1,522
	12	12	9,423	1,958	1,586
Feb. 21	Am	Pm			
	7	5	1,201	250	203
	8	4	4,099	852	690
	9	3	6,749	1,402	1,136
	10	2	8,728	1,813	1,469
	11	1	9,999	2,077	1,682
	12	12	10,388	2,158	1,748
Mar. 21	Am	Pm			
	7	5	1,507	313	254
	8	4	4,520	939	761
	9	3	7,138	1,483	1,201
	10	2	9,183	1,908	1,545
	11	1	10,402	2,161	1,750
	12	12	10,761	2,236	1,811
Apr.21	Am	Pm			
	7	5	1,636	340	275
	8	4	4,385	911	738
	9	3	6,786	1,410	1,142
	10	2	8,631	1,793	1,452
	11	1	9,709	2,017	1,634
	12	12	10,057	2,089	1,692

Hor. Irrad. Gr fl 40' fm. wind.

			Average Outdoor	Final Daylight Factor (Df*dfwqg/dfgrass)	ittance Through Lo_E
			Horizontal Irradince	0.20775	0.81
May.21	Am	Pm	(Foot Candle)	(Foot Candle)	(Foot Candle)
	7	5	1,606	334	271
	8	4	3,983	827	828
	9	3	5,878	1,221	989
	10	2	7,388	1,535	1,243
	11	1	8,577	1,782	1,443
	12	12	8,898	1,849	1,498
Jun.21	Am	Pm			
	7	5	1,338	278	225
	8	4	3,239	673	545
	9	3	4,899	1,018	825
	10	2	6,157	1,279	1,036
	11	1	6,960	1,446	1,171
	12	12	7,201	1,496	1,212
Jul.21	Am	Pm			
	7	5	1,443	300	243
	8	4	3,592	746	604
	9	3	5,418	1,126	912
	10	2	6,861	1,425	1,154
	11	1	7,715	1,603	1,298
	12	12	8,009	1,664	1,348
Aug.21	Am	Pm			
	7	5	1,434	298	241
	8	4	3,753	780	632
	9	3	5,798	1,205	976
	10	2	7,354	1,528	1,238
	11	1	8,300	1,724	1,396
	12	12	8,605	1,788	1,448

Hor. Irrad. Gr fl 40' fm. wind.

			Average Outdoor	Final Daylight Factor (Df*dfwqg/dfgrass)	ittance Through Lo_E
			Horizontal Irradince	0.20775	0.81
Sep.21	Am	Pm	(Foot Candle)	(Foot Candle)	(Foot Candle)
	7	5	1,207	251	203
	8	4	3,563	740	599
	9	3	5,683	1,181	957
	10	2	7,273	1,511	1,224
	11	1	8,245	1,713	1,388
	12	12	8,539	1,774	1,437
Oct.21	Am	Pm			
	7	5	1,019	212	172
	8	4	3,388	704	570
	9	3	5,576	1,158	938
	10	2	7,255	1,507	1,221
	11	1	8,305	1,725	1,397
	12	12	8,634	1,794	1,453
Nov.21	Am	Pm			
	7	5	779	162	131
	8	4	3,028	629	509
	9	3	5,187	1,078	873
	10	2	6,806	1,414	1,145
	11	1	7,825	1,626	1,317
	12	12	8,185	1,700	1,377
Dec.21	Am	Pm			
	7	5	671	139	113
	8	4	2,869	596	483
	9	3	5,066	1,052	852
	10	2	6,683	1,388	1,124
	11	1	7,721	1,604	1,299
	12	12	8,087	1,680	1,361

DAYLIGHT FACTOR : 45FT. FROM WINDOW

GROUND FLOOR

CEILING:
90% OF 5000 SQ. FT. = 4500 SQ. FT.
FLOOR :
50% OF 5000 SQ. FT. = 2500 SQ. FT.
VERTICAL WALL :
90% OF 5000 SQ. FT. = 4500 SQ. FT.
GLASS WALL :
15% OF 2500 SQ. FT. = 375 SQ. FT.
TOTAL SurfaceAREA = Aceiling+Afloor+Awall+Aglass wall
= 5000+5000+5000+2500 SQ. FT.
= 17500 SQ. FT.
AVERAGE REFLECTANCE FACTOR = 11875 SQ. FT./17500 SQ. FT.
= .68 OR 68%

Aimaginary window 2500 SQ. FT.
.... = ...
TOTAL SURFACE AREA 17500 SQ. FT.
= 0.14
SO, INTERNAL REFLECTANCE COMPONENT OF DAYLIGHT FACTOR
= 10%
SKY COMPONENT = 2.52%
EXTERNAL REFLECTED COMP'T. = 10% OF SKY COMPONENT
= 0.252%
DAYLIGHT FACTOR = 12.772%
$DF*DF_{\text{white quartz gravel}}/DF_{\text{grass}}$ (Final Daylight Factor) = 12.772*1.46
= 18.6%

Hor. Irrad. Gr fl 45' fm. wind.

			Average Outdoor Horizontal Irradince (Foot Candle)	Final Daylight Factor (Df*dfwqg/dfgrass) 0.186 (Foot Candle)	Transmittance Through Lo_E 0.81 (Foot Candle)
Jan. 21	Am	Pm			
	7	5	891	166	134
	8	4	3,495	650	527
	9	3	5,962	1,109	898
	10	2	7,846	1,459	1,182
	11	1	9,046	1,683	1,363
	12	12	9,423	1,753	1,420
Feb. 21	Am	Pm			
	7	5	1,201	223	181
	8	4	4,099	762	617
	9	3	6,749	1,255	1,017
	10	2	8,728	1,623	1,315
	11	1	9,999	1,860	1,507
	12	12	10,388	1,932	1,565
Mar. 21	Am	Pm			
	7	5	1,507	280	227
	8	4	4,520	841	681
	9	3	7,138	1,328	1,076
	10	2	9,183	1,708	1,383
	11	1	10,402	1,935	1,567
	12	12	10,761	2,002	1,622
Apr.21	Am	Pm			
	7	5	1,636	304	246
	8	4	4,385	816	661
	9	3	6,786	1,262	1,022
	10	2	8,631	1,605	1,300
	11	1	9,709	1,806	1,463
	12	12	10,057	1,871	1,516

Hor. Irrad. Gr fl 45' fm. wind.

			Average Outdoor Horizontal Irradince (Foot Candle)	Final Daylight Factor (Df*dfwqg/dfgrass) 0.186 (Foot Candle)	Transmittance Through Lo_E 0.81 (Foot Candle)
May.21	Am	Pm			
	7	5	1,606	299	242
	8	4	3,983	741	742
	9	3	5,878	1,093	885
	10	2	7,388	1,374	1,113
	11	1	8,577	1,595	1,292
	12	12	8,898	1,655	1,341
Jun.21	Am	Pm			
	7	5	1,338	249	202
	8	4	3,239	602	488
	9	3	4,899	911	738
	10	2	6,157	1,145	927
	11	1	6,960	1,295	1,049
	12	12	7,201	1,339	1,085
Jul.21	Am	Pm			
	7	5	1,443	268	217
	8	4	3,592	668	541
	9	3	5,418	1,008	816
	10	2	6,861	1,276	1,034
	11	1	7,715	1,435	1,162
	12	12	8,009	1,490	1,207
Aug.21	Am	Pm			
	7	5	1,434	267	216
	8	4	3,753	698	565
	9	3	5,798	1,078	873
	10	2	7,354	1,368	1,108
	11	1	8,300	1,544	1,251
	12	12	8,605	1,601	1,297

Hor. Irrad. Gr fl 45' fm. wind.

Sep.21	Am	Pm	Average Outdoor Horizontal Irradince (Foot Candle)	Final Daylight Factor (Df*dfwqg/dfgrass) 0.186 (Foot Candle)	Transmittance Through Lo_E 0.81 (Foot Candle)
	7	5	1,207	225	182
	8	4	3,563	663	537
	9	3	5,683	1,057	856
	10	2	7,273	1,353	1,096
	11	1	8,245	1,534	1,243
	12	12	8,539	1,588	1,286
Oct.21	Am	Pm			
	7	5	1,019	190	154
	8	4	3,388	630	510
	9	3	5,576	1,037	840
	10	2	7,255	1,349	1,093
	11	1	8,305	1,545	1,251
	12	12	8,634	1,606	1,301
Nov.21	Am	Pm			
	7	5	779	145	117
	8	4	3,028	563	456
	9	3	5,187	965	782
	10	2	6,806	1,266	1,025
	11	1	7,825	1,455	1,179
	12	12	8,185	1,522	1,233
Dec.21	Am	Pm			
	7	5	671	125	101
	8	4	2,869	534	433
	9	3	5,066	942	763
	10	2	6,683	1,243	1,007
	11	1	7,721	1,436	1,163
	12	12	8,087	1,504	1,218

DAYLIGHT FACTOR : 5FT FROM WINDOW

FIRST FLOOR

CEILING:
90% OF 3000 SQ. FT. = 2700 SQ. FT.
FLOOR :
50% OF 3000 SQ. FT. = 1500 SQ. FT.
VERTICAL WALLS :
90% OF 3200 SQ. FT. = 2880 SQ. FT.
GLASS WALL :
15% OF 2000 SQ. FT. = 300 SQ. FT.
TOTAL Surface AREA = Aceiling+Afloor+Awall+Aglass wall
= 3000+3000+3200 SQ. FT+ 2000SQ. FT.
= 11200 SQ. FT.
AVERAGE REFLECTANCE FACTOR = 7380 SQ. FT./11200 SQ. FT.
= .66 OR 66%

Aglass wall 2000 SQ. FT.
.... = ...
TOTAL SURFACE AREA 11200 SQ. FT.
= 0.16
SO, INTERNAL REFLECTANCE COMPONENT OF DAYLIGHT FACTOR
= 11.5%
SKY COMPONENT = 25.5%
EXTERNAL REFLECTED COMPONENT:
= 10% OF SKY COMPONENT
= 2.55%
DAYLIGHT FACTOR = 39.55%
D.F.*$DF_{\text{white quartz gravel}}/DF_{\text{grass}}$ (Final Daylight Factor) = 39.55*1.23
=48.6%

Hor. Irrad. 1st fl 5' fm. wind.

Jan. 21	Am	Pm	Average Outdoor Horizontal Irradince (Foot Candle)	Final Daylight Factor (Df*dfwqg/dfgrass) 0.486 (Foot Candle)	Transmittance Through Lo_E 0.81 (Foot Candle)
	7	5	891	433	351
	8	4	3,495	1,699	1,376
	9	3	5,962	2,898	2,347
	10	2	7,846	3,813	3,089
	11	1	9,046	4,396	3,561
	12	12	9,423	4,580	3,710
Feb. 21	Am	Pm			
	7	5	1,201	584	443
	8	4	4,099	1,992	1,614
	9	3	6,749	3,280	2,489
	10	2	8,728	4,242	3,436
	11	1	9,999	4,860	3,937
	12	12	10,388	5,049	4,090
Mar. 21	Am	Pm			
	7	5	1,507	732	593
	8	4	4,520	2,197	1,780
	9	3	7,138	3,469	2,810
	10	2	9,183	4,463	3,615
	11	1	10,402	5,055	4,095
	12	12	10,761	5,230	4,236
Apr.21	Am	Pm			
	7	5	1,636	795	644
	8	4	4,385	2,131	1,726
	9	3	6,786	3,298	2,671
	10	2	8,631	4,195	3,398
	11	1	9,709	4,719	3,822
	12	12	10,057	4,888	3,959

Hor. Irrad. 1st fl 5' fm. wind.

May.21	Am	Pm	Average Outdoor Horizontal Irradince (Foot Candle)	Final Daylight Factor (Df*dfwqg/dfgrass) 0.486 (Foot Candle)	Transmittance Through Lo_E 0.81 (Foot Candle)
	7	5	1,606	781	633
	8	4	3,983	1,936	1,568
	9	3	5,878	2,857	2,314
	10	2	7,388	3,591	2,909
	11	1	8,577	4,168	3,376
	12	12	8,898	4,324	3,502
Jun.21	Am	Pm			
	7	5	1,338	650	527
	8	4	3,239	1,574	1,275
	9	3	4,899	2,381	1,929
	10	2	6,157	2,992	2,424
	11	1	6,960	3,383	2,740
	12	12	7,201	3,500	2,835
Jul.21	Am	Pm			
	7	5	1,443	701	532
	8	4	3,592	1,746	1,414
	9	3	5,418	2,633	2,133
	10	2	6,861	3,334	2,701
	11	1	7,715	3,749	3,037
	12	12	8,009	3,892	3,153
Aug.21	Am	Pm			
	7	5	1,434	697	565
	8	4	3,753	1,824	1,477
	9	3	5,798	2,818	2,283
	10	2	7,354	3,574	2,895
	11	1	8,300	4,034	3,268
	12	12	8,605	4,182	3,387

Hor. Irrad. 1st fl 5' fm. wind.

	Am	Pm	Average Outdoor Horizontal Irradince (Foot Candle)	Final Daylight Factor (Df*dfwqg/dfgrass) 0.486 (Foot Candle)	Transmittance Through Lo_E 0.81 (Foot Candle)
Sept.21	Am	Pm			
	7	5	1,207	587	475
	8	4	3,563	1,732	1,403
	9	3	5,683	2,762	2,237
	10	2	7,273	3,535	2,863
	11	1	8,245	4,007	3,246
	12	12	8,539	4,150	3,362
Oct.21	Am	Pm			
	7	5	1,019	495	401
	8	4	3,388	1,647	1,250
	9	3	5,576	2,710	2,195
	10	2	7,255	3,526	2,856
	11	1	8,305	4,036	3,269
	12	12	8,634	4,196	3,399
Nov.21	Am	Pm			
	7	5	779	379	307
	8	4	3,028	1,472	1,192
	9	3	5,187	2,521	2,042
	10	2	6,806	3,308	2,679
	11	1	7,825	3,803	3,080
	12	12	8,185	3,978	3,222
Dec.21	Am	Pm			
	7	5	671	326	264
	8	4	2,869	1,394	1,129
	9	3	5,066	2,462	1,994
	10	2	6,683	3,248	2,631
	11	1	7,721	3,752	3,039
	12	12	8,087	3,930	3,183

DAYLIGHT FACTOR : 10FT FROM WINDOW

FIRST FLOOR

CEILING:
90% OF 3000 SQ. FT. = 2700 SQ. FT.
FLOOR :
50% OF 3000 SQ. FT. = 1500 SQ. FT.
VERTICAL WALLS :
90% OF 3200 SQ. FT. = 2880 SQ. FT.
GLASS WALL :
15% OF 2000 SQ. FT. = 300 SQ. FT.
TOTAL Surface AREA = Aceiling+Afloor+Awall+Aglass wall
= 3000+3000+3200 SQ. FT.+2000SQ. FT.
= 11200 SQ. FT.
AVERAGE REFLECTANCE FACTOR = 7380 SQ. FT./11200 SQ. FT.
= .66 OR 66%

Aglass wall 2000 SQ. FT.
.... = ...
TOTAL SURFACE AREA 11200 SQ. FT.
= 0.16
SO, INTERNAL REFLECTANCE COMPONENT OF DAYLIGHT FACTOR
= 11.5%
SKY COMPONENT = 17.46%
EXTERNAL REFLECTED COMPONENT:
= 10% OF SKY COMPONENT
= 1.746%
DAYLIGHT FACTOR = 30.7%
$D.F.*DF_{\text{white quartz grave}}l/DF_{\text{grass}}$ (Final Daylight Factor) = 30.7*1.5
=46.1%

Hor. Irrad. 1st fl 10' fm. win

Jan. 21	Am	Pm	Average Outdoor Horizontal Irradince (Foot Candle)	Final Daylight Factor (Df*dfwqg/dfgrass) 0.461 (Foot Candle)	Transmittance Through Lo_E 0.81 (Foot Candle)
	7	5	891	411	333
	8	4	3,495	1,611	1,305
	9	3	5,962	2,748	2,226
	10	2	7,846	3,617	2,930
	11	1	9,046	4,170	3,378
	12	12	9,423	4,344	3,519
Feb. 21	Am	Pm			
	7	5	1,201	554	449
	8	4	4,099	1,890	1,531
	9	3	6,749	3,111	2,520
	10	2	8,728	4,024	3,259
	11	1	9,999	4,610	3,734
	12	12	10,388	4,789	3,879
Mar. 21	Am	Pm			
	7	5	1,507	695	556
	8	4	4,520	2,084	1,688
	9	3	7,138	3,291	2,666
	10	2	9,183	4,233	3,429
	11	1	10,402	4,795	3,884
	12	12	10,761	4,961	4,018
Apr.21	Am	Pm			
	7	5	1,636	754	611
	8	4	4,385	2,021	1,637
	9	3	6,786	3,128	2,534
	10	2	8,631	3,979	3,223
	11	1	9,709	4,476	3,626
	12	12	10,057	4,636	3,755

Hor. Irrad. 1st fl 10' fm. win

	Am	Pm	Average Outdoor Horizontal Irradince (Foot Candle)	Final Daylight Factor (Df*dfwqg/dfgrass) 0.461 (Foot Candle)	Transmittance Through Lo_E 0.81 (Foot Candle)
May.21	Am	Pm			
	7	5	1,606	740	599
	8	4	3,983	1,836	1,487
	9	3	5,878	2,710	2,168
	10	2	7,388	3,406	2,759
	11	1	8,577	3,954	3,203
	12	12	8,898	4,102	3,323
Jun.21	Am	Pm			
	7	5	1,338	617	500
	8	4	3,239	1,493	1,209
	9	3	4,899	2,258	1,829
	10	2	6,157	2,838	2,299
	11	1	6,960	3,209	2,599
	12	12	7,201	3,320	2,689
Jul.21	Am	Pm			
	7	5	1,443	665	539
	8	4	3,592	1,656	1,341
	9	3	5,418	2,498	2,023
	10	2	6,861	3,163	2,562
	11	1	7,715	3,557	2,881
	12	12	8,009	3,692	2,991
Aug.21	Am	Pm			
	7	5	1,434	661	535
	8	4	3,753	1,730	1,401
	9	3	5,798	2,673	2,165
	10	2	7,354	3,390	2,746
	11	1	8,300	3,826	3,099
	12	12	8,605	3,967	3,213

Hor. Irrad. 1st fl 10' fm. win

	Am	Pm	Average Outdoor Horizontal Irradince (Foot Candle)	Final Daylight Factor (Df*dfwqg/dfgrass) 0.461 (Foot Candle)	Transmittance Through Lo_E 0.81 (Foot Candle)
Sep.21	Am	Pm			
	7	5	1,207	556	450
	8	4	3,563	1,643	1,331
	9	3	5,683	2,620	2,122
	10	2	7,273	3,353	2,716
	11	1	8,245	3,801	3,079
	12	12	8,539	3,936	3,188
Oct.21	Am	Pm			
	7	5	1,019	470	381
	8	4	3,388	1,562	1,265
	9	3	5,576	2,571	2,083
	10	2	7,255	3,345	2,709
	11	1	8,305	3,829	3,101
	12	12	8,634	3,980	3,224
Nov.21	Am	Pm			
	7	5	779	359	291
	8	4	3,028	1,396	1,131
	9	3	5,187	2,391	1,937
	10	2	6,806	3,138	2,542
	11	1	7,825	3,607	2,922
	12	12	8,185	3,773	3,056
Dec.21	Am	Pm			
	7	5	671	309	250
	8	4	2,869	1,323	1,072
	9	3	5,066	2,335	1,891
	10	2	6,683	3,081	2,496
	11	1	7,721	3,559	2,883
	12	12	8,087	3,728	3,020

DAYLIGHT FACTOR : 15FT FROM WINDOW

FIRST FLOOR

CEILING:

90% OF 3000 SQ. FT. = 2700 SQ. FT.

FLOOR :

50% OF 3000 SQ. FT. = 1500 SQ. FT.

VERTICAL WALLS :

90% OF 3200 SQ. FT. = 2880 SQ. FT.

GLASS WALL :

15% OF 2000 SQ. FT. = 300 SQ. FT.

TOTAL Surface AREA = Aceiling+Afloor+Awall+Aglass wall
= 3000+3000+3200 SQ. FT.+2000SQ. FT.
= 11200 SQ. FT.

AVERAGE REFLECTANCE FACTOR = 7380 SQ. FT./11200 SQ. FT.
= .66 OR 66%

Aglass wall / TOTAL SURFACE AREA = 2000 SQ. FT. / 11200 SQ. FT.
= 0.18

SO, INTERNAL REFLECTANCE COMPONENT OF DAYLIGHT FACTOR
= 11.5%

SKY COMPONENT = 12.1%

EXTERNAL REFLECTED COMPONENT:
= 10% OF SKY COMPONENT
= 1.21%

DAYLIGHT FACTOR = 24.81%

$DF*DF_{\text{white quartz grave}}l/Df_{\text{grass}}$ (Final Daylight Factor) = 24.81*1.5
= 37.2%

Hor. Irrad. 1st fl 15' fm. wind

Jan. 21	Am	Pm	Average Outdoor Horizontal Irradince (Foot Candle)	Final Daylight Factor (Df*dfwqg/dfgrass) 0.372 (Foot Candle)	Transmittance Through Lo_E 0.81 (Foot Candle)
	7	5	891	331	268
	8	4	3,495	1,300	1,053
	9	3	5,962	2,218	1,797
	10	2	7,846	2,919	2,364
	11	1	9,046	3,365	2,726
	12	12	9,423	3,505	2,839
Feb. 21	Am	Pm			
	7	5	1,201	447	362
	8	4	4,099	1,525	1,235
	9	3	6,749	2,511	2,034
	10	2	8,728	3,247	2,630
	11	1	9,999	3,720	3,013
	12	12	10,388	3,864	3,130
Mar. 21	Am	Pm			
	7	5	1,507	561	454
	8	4	4,520	1,681	1,362
	9	3	7,138	2,655	2,151
	10	2	9,183	3,416	2,767
	11	1	10,402	3,870	3,135
	12	12	10,761	4,003	3,242
Apr.21	Am	Pm			
	7	5	1,636	609	493
	8	4	4,385	1,631	1,321
	9	3	6,786	2,524	2,044
	10	2	8,631	3,211	2,601
	11	1	9,709	3,612	2,926
	12	12	10,057	3,741	3,030

Hor. Irrad. 1st fl 15' fm. wind

	Am	Pm	Average Outdoor Horizontal Irradince (Foot Candle)	Final Daylight Factor (Df*dfwqg/dfgrass) 0.372 (Foot Candle)	Transmittance Through Lo_E 0.81 (Foot Candle)
May.21	Am	Pm			
	7	5	1,606	597	484
	8	4	3,983	1,482	1,200
	9	3	5,878	2,187	1,771
	10	2	7,388	2,748	2,226
	11	1	8,577	3,191	2,585
	12	12	8,898	3,310	2,681
Jun.21	Am	Pm			
	7	5	1,338	498	403
	8	4	3,239	1,205	976
	9	3	4,899	1,822	1,476
	10	2	6,157	2,290	1,855
	11	1	6,960	2,589	2,097
	12	12	7,201	2,679	2,170
Jul.21	Am	Pm			
	7	5	1,443	537	435
	8	4	3,592	1,336	1,082
	9	3	5,418	2,015	1,632
	10	2	6,861	2,552	2,067
	11	1	7,715	2,870	2,325
	12	12	8,009	2,979	2,413
Aug.21	Am	Pm			
	7	5	1,434	533	432
	8	4	3,753	1,396	1,131
	9	3	5,798	2,157	1,747
	10	2	7,354	2,736	2,216
	11	1	8,300	3,088	2,501
	12	12	8,605	3,201	2,593

Hor. Irrad. 1st fl 15' fm. wind

			Average Outdoor Horizontal Irradince (Foot Candle)	Final Daylight Factor (Df*dfwqg/dfgrass) 0.372 (Foot Candle)	Transmittance Through Lo_E 0.81 (Foot Candle)
Sep.21	Am	Pm			
	7	5	1,207	449	364
	8	4	3,563	1,325	1,073
	9	3	5,683	2,114	1,712
	10	2	7,273	2,706	2,192
	11	1	8,245	3,067	2,484
	12	12	8,539	3,177	2,573
Oct.21	Am	Pm			
	7	5	1,019	379	307
	8	4	3,388	1,260	1,021
	9	3	5,576	2,074	1,680
	10	2	7,255	2,699	2,186
	11	1	8,305	3,089	2,502
	12	12	8,634	3,212	2,602
Nov.21	Am	Pm			
	7	5	779	290	235
	8	4	3,028	1,126	912
	9	3	5,187	1,930	1,563
	10	2	6,806	2,532	2,051
	11	1	7,825	2,911	2,358
	12	12	8,185	3,045	2,466
Dec.21	Am	Pm			
	7	5	671	250	203
	8	4	2,869	1,067	864
	9	3	5,066	1,885	1,527
	10	2	6,683	2,486	2,014
	11	1	7,721	2,872	2,326
	12	12	8,087	3,008	2,436

DAYLIGHT FACTOR : 20FT. FROM WINDOW

FIRST FLOOR

CEILING:
90% OF 3000 SQ. FT. = 2700 SQ. FT.
FLOOR :
50% OF 3000 SQ. FT. = 1500 SQ. FT.
VERTICAL WALLS :
90% OF 3200 SQ. FT. = 2880 SQ. FT.
GLASS WALL :
15% OF 2000 SQ. FT. = 300 SQ. FT.
TOTAL Surface AREA = Aceiling+Afloor+Awall+Aglass wall
= 3000+3000+3200 SQ. FT.+2000SQ. FT.
= 11,200 SQ. FT.
AVERAGE REFLECTANCE FACTOR = 7380 SQ. FT./11200 SQ. FT.
= .66 OR 66%

$$\frac{\text{Aglass wall}}{\text{TOTAL SURFACE AREA}} = \frac{\text{2000 SQ. FT.}}{\text{11200 SQ. FT.}}$$

= 0.18

SO, INTERNAL REFLECTANCE COMPONENT OF DAYLIGHT FACTOR
= 11.5%
SKY COMPONENT = 8.2%
EXTERNAL REFLECTED COMPONENT:
= 10% OF SKY COMPONENT
= 0.82%
DAYLIGHT FACTOR = 20.52%
$DF*DF_{\text{white quartz gravel}}/DF_{\text{grass}}$ (Final Daylight Factor) = 20.52*1.6
= 32.8%

Hor. Irrad. 1st fl 20' fm. wind

	Am	Pm	Average Outdoor Horizontal Irradince (Foot Candle)	Final Daylight Factor (Df*dfwqg/dfgrass) 0.328 (Foot Candle)	Transmittance Through Lo_E 0.81 (Foot Candle)
Jan. 21	Am	Pm			
	7	5	891	292	237
	8	4	3,495	1,146	928
	9	3	5,962	1,956	1,584
	10	2	7,846	2,573	2,084
	11	1	9,046	2,967	2,403
	12	12	9,423	3,091	2,504
Feb. 21	Am	Pm			
	7	5	1,201	394	319
	8	4	4,099	1,344	1,089
	9	3	6,749	2,214	1,793
	10	2	8,728	2,863	2,319
	11	1	9,999	3,280	2,657
	12	12	10,388	3,407	2,760
Mar. 21	Am	Pm			
	7	5	1,507	494	400
	8	4	4,520	1,483	1,201
	9	3	7,138	2,341	1,896
	10	2	9,183	3,012	2,440
	11	1	10,402	3,412	2,764
	12	12	10,761	3,530	2,859
Apr.21	Am	Pm			
	7	5	1,636	537	435
	8	4	4,385	1,438	1,165
	9	3	6,786	2,226	1,803
	10	2	8,631	2,831	2,293
	11	1	9,709	3,185	2,580
	12	12	10,057	3,299	2,672

Hor. Irrad. 1st fl 20' fm. wind

			Average Outdoor	Final Daylight Factor (Df*dfwqg/dfgrass)	Transmittance Through Lo_E
			Horizontal Irradince	0.328	0.81
May.21	Am	Pm	(Foot Candle)	(Foot Candle)	(Foot Candle)
	7	5	1,606	527	427
	8	4	3,983	1,306	1,058
	9	3	5,878	1,928	1,562
	10	2	7,388	2,423	1,963
	11	1	8,577	2,813	2,279
	12	12	8,898	2,919	2,364
Jun.21	Am	Pm			
	7	5	1,338	439	356
	8	4	3,239	1,062	860
	9	3	4,899	1,607	1,302
	10	2	6,157	2,019	1,635
	11	1	6,960	2,283	1,849
	12	12	7,201	2,362	1,913
Jul.21	Am	Pm			
	7	5	1,443	473	383
	8	4	3,592	1,178	954
	9	3	5,418	1,777	1,439
	10	2	6,861	2,250	1,823
	11	1	7,715	2,531	2,050
	12	12	8,009	2,627	2,128
Aug.21	Am	Pm			
	7	5	1,434	470	381
	8	4	3,753	1,231	997
	9	3	5,798	1,902	1,541
	10	2	7,354	2,412	1,954
	11	1	8,300	2,722	2,205
	12	12	8,605	2,822	2,286

Hor. Irrad. 1st fl 20' fm. wind

			Average Outdoor Horizontal Irradince	Final Daylight Factor (Df*dfwqg/dfgrass) 0.328	Transmittance Through Lo_E 0.81
Sep.21	Am	Pm	(Foot Candle)	(Foot Candle)	(Foot Candle)
	7	5	1,207	396	321
	8	4	3,563	1,169	947
	9	3	5,683	1,864	1,510
	10	2	7,273	2,386	1,933
	11	1	8,245	2,704	2,190
	12	12	8,539	2,801	2,269
Oct.21	Am	Pm			
	7	5	1,019	334	271
	8	4	3,388	1,111	900
	9	3	5,576	1,829	1,481
	10	2	7,255	2,380	1,928
	11	1	8,305	2,724	2,206
	12	12	8,634	2,832	2,294
Nov.21	Am	Pm			
	7	5	779	256	631
	8	4	3,028	993	804
	9	3	5,187	1,701	1,378
	10	2	6,806	2,232	1,808
	11	1	7,825	2,567	2,079
	12	12	8,185	2,685	2,175
Dec.21	Am	Pm			
	7	5	671	220	178
	8	4	2,869	941	762
	9	3	5,066	1,662	1,346
	10	2	6,683	2,192	1,776
	11	1	7,721	2,532	2,051
	12	12	8,087	2,653	2,149

DAYLIGHT FACTOR : 25FT FROM WINDOW

FIRST FLOOR

CEILING:
90% OF 3000 SQ. FT. = 2700 SQ. FT.
FLOOR :
50% OF 3000 SQ. FT. = 1500 SQ. FT.
VERTICAL WALLS:
90% OF 3200 SQ. FT. = 2880 SQ. FT.
GLASS WALL :
15% OF 2000 SQ. FT. = 300 SQ. FT.
TOTAL Surface AREA = Aceiling+Afloor+Awalls+Aglass wall
= 3000+3000+3200 SQ. FT.+2000SQ. FT.
= 11,200 SQ. FT.
AVERAGE REFLECTANCE FACTOR = 7,380 SQ. FT./11,200 SQ. FT.
= .66 OR 66%

Aglass wall 2000 SQ. FT.
.... = ...
TOTAL SURFACE AREA 11,200 SQ. FT.
= 0.18
SO, INTERNAL REFLECTANCE COMPONENT OF DAYLIGHT FACTOR
= 11.5%
SKY COMPONENT = 5.76%
EXTERNAL REFLECTED COMPONENT:
= 10% OF SKY COMPONENT
= 0.576%
DAYLIGHT FACTOR =17.8%
$DF*DF_{\text{white quartz gravel}}/DF_{\text{grass}}$ (Final Daylight Factor) =17.8*1.6
=28.48%

Hor. Irrad. 1st fl 25' fm. wind

			Average Outdoor Horizontal Irradince (Foot Candle)	Final Daylight Factor (Df*dfwqg/dfgrass) 0.2848 (Foot Candle)	Transmittance Through Lo_E 0.81 (Foot Candle)
Jan. 21	Am	Pm			
	7	5	891	254	206
	8	4	3,495	995	806
	9	3	5,962	1,698	1,375
	10	2	7,846	2,235	1,810
	11	1	9,046	2,576	2,087
	12	12	9,423	2,684	2,174
Feb. 21	Am	Pm			
	7	5	1,201	342	277
	8	4	4,099	1,167	945
	9	3	6,749	1,922	1,557
	10	2	8,728	2,486	2,014
	11	1	9,999	2,848	2,307
	12	12	10,388	2,959	2,397
Mar. 21	Am	Pm			
	7	5	1,507	429	347
	8	4	4,520	1,287	1,042
	9	3	7,138	2,033	1,647
	10	2	9,183	2,615	2,118
	11	1	10,402	2,962	2,399
	12	12	10,761	3,065	2,483
Apr.21	Am	Pm			
	7	5	1,636	466	377
	8	4	4,385	1,249	1,012
	9	3	6,786	1,933	1,566
	10	2	8,631	2,458	1,991
	11	1	9,709	2,765	2,240
	12	12	10,057	2,864	2,320

Hor. Irrad. 1st fl 25' fm. wind

May.21	Am	Pm	Average Outdoor Horizontal Irradince (Foot Candle)	Final Daylight Factor (Df*dfwqg/dfgrass) 0.2848 (Foot Candle)	Transmittance Through Lo_E 0.81 (Foot Candle)
	7	5	1,606	457	370
	8	4	3,983	1,134	919
	9	3	5,878	1,674	1,356
	10	2	7,388	2,104	1,704
	11	1	8,577	2,443	1,979
	12	12	8,898	2,534	2,053
Jun.21	Am	Pm			
	7	5	1,338	381	309
	8	4	3,239	922	747
	9	3	4,899	1,395	1,130
	10	2	6,157	1,754	1,421
	11	1	6,960	1,982	1,605
	12	12	7,201	2,051	1,661
Jul.21	Am	Pm			
	7	5	1,443	411	333
	8	4	3,592	1,023	829
	9	3	5,418	1,543	1,250
	10	2	6,861	1,954	1,583
	11	1	7,715	2,197	1,780
	12	12	8,009	2,281	1,848
Aug.21	Am	Pm			
	7	5	1,434	408	330
	8	4	3,753	1,069	866
	9	3	5,798	1,651	1,337
	10	2	7,354	2,094	1,696
	11	1	8,300	2,364	1,915
	12	12	8,605	2,451	1,985

Hor. Irrad. 1st fl 25' fm. wind

	Am	Pm	Average Outdoor Horizontal Irradince (Foot Candle)	Final Daylight Factor (Df*dfwqg/dfgrass) 0.2848 (Foot Candle)	Transmittance Through Lo_E 0.81 (Foot Candle)
Sep.21	Am	Pm			
	7	5	1,207	344	279
	8	4	3,563	1,015	822
	9	3	5,683	1,619	1,311
	10	2	7,273	2,071	1,678
	11	1	8,245	2,348	1,902
	12	12	8,539	2,432	1,970
Oct.21	Am	Pm			
	7	5	1,019	290	235
	8	4	3,388	965	782
	9	3	5,576	1,588	1,286
	10	2	7,255	2,066	1,673
	11	1	8,305	2,365	1,916
	12	12	8,634	2,459	1,992
Nov.21	Am	Pm			
	7	5	779	222	180
	8	4	3,028	862	698
	9	3	5,187	1,477	1,196
	10	2	6,806	1,938	1,570
	11	1	7,825	2,229	1,805
	12	12	8,185	2,331	1,888
Dec.21	Am	Pm			
	7	5	671	191	155
	8	4	2,869	817	662
	9	3	5,066	1,443	1,169
	10	2	6,683	1,903	1,541
	11	1	7,721	2,199	1,781
	12	12	8,087	2,303	1,865

DAYLIGHT FACTOR : 5T. FROM WINDOW

2ND. FLOOR

CEILING:
90% OF 2000 SQ. FT. = 1800 SQ. FT.
FLOOR :
50% OF 2000 SQ. FT. = 1000 SQ. FT.
VERTICAL WALLS :
90% OF 600 SQ. FT. = 540 SQ. FT.
GLASS WALL :
15% OF 1500 SQ. FT. = 225 SQ. FT.
TOTAL SurfaceAREA = Aceiling+Afloor+Awall+Aglass wall
= 2000+2000+600+1500 SQ. FT.
= 17500 SQ. FT.
AVERAGE REFLECTANCE FACTOR = 3565 SQ. FT./6100 SQ. FT.
= .58 OR 58%

Aimaginary window 1500 SQ. FT.
.... = ...
TOTAL SURFACE AREA 6100 SQ. FT.
= 0.25
SO, INTERNAL REFLECTANCE COMPONENT OF DAYLIGHT FACTOR
= 11.5%
SKY COMPONENT = 22.8%
EXTERNAL REFLECTED COMP'T. = 10% OF SKY COMPONENT
= 2.28%
DAYLIGHT FACTOR = 36.58%
$DF*DF_{\text{white quartz gravel}}/DF_{\text{grass}}$ (Final Daylight Factor) = 36.58*1.39
= 50.8%

Hor. Irrad 2nd fl 5' fm. wind.

			Average Outdoor Horizontal Irradince	Final Daylight Factor (Df*dfwqg/dfgrass) 0.508	Transmittance Through Lo_E 0.81
Jan. 21	Am	Pm	(Foot Candle)	(Foot Candle)	(Foot Candle)
	7	5	891	453	367
	8	4	3,495	1,775	1,438
	9	3	5,962	3,029	2,453
	10	2	7,846	3,986	3,229
	11	1	9,046	4,595	3,722
	12	12	9,423	4,787	3,877
Feb. 21	Am	Pm			
	7	5	1,201	610	494
	8	4	4,099	2,082	1,686
	9	3	6,749	3,428	2,777
	10	2	8,728	4,434	3,592
	11	1	9,999	5,079	4,114
	12	12	10,388	5,277	4,274
Mar. 21	Am	Pm			
	7	5	1,507	766	620
	8	4	4,520	2,296	1,860
	9	3	7,138	3,626	2,937
	10	2	9,183	4,665	3,779
	11	1	10,402	5,284	4,280
	12	12	10,761	5,467	4,428
Apr.21	Am	Pm			
	7	5	1,636	831	673
	8	4	4,385	2,228	1,805
	9	3	6,786	3,447	2,792
	10	2	8,631	4,385	3,552
	11	1	9,709	4,932	3,995
	12	12	10,057	5,109	4,138

Hor. Irrad 2nd fl 5' fm. wind.

	Am	Pm	Average Outdoor Horizontal Irradince (Foot Candle)	Final Daylight Factor (Df*dfwqg/dfgrass) 0.508 (Foot Candle)	Transmittance Through Lo_E 0.81 (Foot Candle)
May.21					
	7	5	1,606	816	661
	8	4	3,983	2,023	1,639
	9	3	5,878	2,986	2,419
	10	2	7,388	3,753	3,040
	11	1	8,577	4,357	3,529
	12	12	8,898	4,520	3,661
Jun.21	Am	Pm			
	7	5	1,338	680	551
	8	4	3,239	1,645	1,332
	9	3	4,899	2,489	2,016
	10	2	6,157	3,128	2,534
	11	1	6,960	3,536	2,864
	12	12	7,201	3,658	2,963
Jul.21	Am	Pm			
	7	5	1,443	733	594
	8	4	3,592	1,825	1,478
	9	3	5,418	2,752	2,229
	10	2	6,861	3,485	2,823
	11	1	7,715	3,919	3,174
	12	12	8,009	4,069	3,296
Aug.21	Am	Pm			
	7	5	1,434	728	590
	8	4	3,753	1,907	1,545
	9	3	5,798	2,945	2,385
	10	2	7,354	3,736	3,026
	11	1	8,300	4,216	3,415
	12	12	8,605	4,371	3,541

Hor. Irrad 2nd fl 5' fm. wind.

Sep.21	Am	Pm	Average Outdoor Horizontal Irradince (Foot Candle)	Final Daylight Factor (Df*dfwqg/dfgrass) 0.508 (Foot Candle)	Transmittance Through Lo_E 0.81 (Foot Candle)
	7	5	1,207	613	497
	8	4	3,563	1,810	1,466
	9	3	5,683	2,887	2,338
	10	2	7,273	3,695	2,993
	11	1	8,245	4,188	3,392
	12	12	8,539	4,338	3,514
Oct.21	Am	Pm			
	7	5	1,019	518	420
	8	4	3,388	1,721	1,394
	9	3	5,576	2,833	2,295
	10	2	7,255	3,686	2,986
	11	1	8,305	4,219	3,417
	12	12	8,634	4,386	3,553
Nov.21	Am	Pm			
	7	5	779	396	321
	8	4	3,028	1,538	1,246
	9	3	5,187	2,635	2,134
	10	2	6,806	3,457	2,800
	11	1	7,825	3,975	3,220
	12	12	8,185	4,158	3,368
Dec.21	Am	Pm			
	7	5	671	341	276
	8	4	2,869	1,457	1,180
	9	3	5,066	2,574	2,085
	10	2	6,683	3,395	2,750
	11	1	7,721	3,922	3,177
	12	12	8,087	4,108	3,327

DAYLIGHT FACTOR : 10FT. FROM WINDOW

2ND. FLOOR

CEILING:
90% OF 2000 SQ. FT. = 1800 SQ. FT.
FLOOR :
50% OF 2000 SQ. FT. = 1000 SQ. FT.
VERTICAL WALLS :
90% OF 600 SQ. FT. = 540 SQ. FT.
GLASS WALL :
15% OF 1500 SQ. FT. = 225 SQ. FT.
TOTAL SurfaceAREA = Aceiling+Afloor+Awall+Aglass wall
= 2000+2000+600+1500 SQ. FT.
= 17500 SQ. FT.
AVERAGE REFLECTANCE FACTOR = 3565 SQ. FT./6100 SQ. FT.
= .58 OR 58%

Aimaginary window 1500 SQ. FT.
.... = ...
TOTAL SURFACE AREA 6100 SQ. FT.
= 0.25
SO, INTERNAL REFLECTANCE COMPONENT OF DAYLIGHT FACTOR
= 11.5%
SKY COMPONENT = 13.7%
EXTERNAL REFLECTED COMP'T. = 10% OF SKY COMPONENT
= 1.37%
DAYLIGHT FACTOR = 26.57%
$DF*DF_{\text{white quartz gravel}}/DF_{\text{grass}}$ (Final Daylight Factor) = 26.57*1.5
= 39.86%

Hor. Irrad 2nd fl 10' fm. wind.

			Average Outdoor Horizontal Irradince	Final Daylight Factor (Df*dfwqg/dfgrass)	Transmittance Through Lo_E
				0.3986	0.81
Jan. 21	Am	Pm	(Foot Candle)	(Foot Candle)	(Foot Candle)
	7	5	891	355	288
	8	4	3,495	1,393	1,128
	9	3	5,962	2,376	1,925
	10	2	7,846	3,127	2,533
	11	1	9,046	3,606	2,921
	12	12	9,423	3,756	3,042
Feb. 21	Am	Pm			
	7	5	1,201	479	388
	8	4	4,099	1,634	1,512
	9	3	6,749	2,690	2,179
	10	2	8,728	3,479	2,818
	11	1	9,999	3,986	3,229
	12	12	10,388	4,141	3,354
Mar. 21	Am	Pm			
	7	5	1,507	601	487
	8	4	4,520	1,802	1,460
	9	3	7,138	2,845	2,304
	10	2	9,183	3,660	2,965
	11	1	10,402	4,146	3,358
	12	12	10,761	4,289	3,474
Apr.21	Am	Pm			
	7	5	1,636	652	528
	8	4	4,385	1,748	1,416
	9	3	6,786	2,705	2,191
	10	2	8,631	3,440	2,786
	11	1	9,709	3,870	3,135
	12	12	10,057	4,009	3,247

Hor. Irrad 2nd fl 10' fm. wind.

			Average Outdoor Horizontal Irradince	Final Daylight Factor (Df*dfwqg/dfgrass) 0.3986	Transmittance Through Lo_E 0.81
May.21	Am	Pm	(Foot Candle)	(Foot Candle)	(Foot Candle)
	7	5	1,606	640	518
	8	4	3,983	1,588	1,286
	9	3	5,878	2,343	1,898
	10	2	7,388	2,945	2,385
	11	1	8,577	3,419	2,769
	12	12	8,898	3,547	2,873
Jun.21	Am	Pm			
	7	5	1,338	533	432
	8	4	3,239	1,291	1,046
	9	3	4,899	1,953	1,582
	10	2	6,157	2,454	1,988
	11	1	6,960	2,774	2,247
	12	12	7,201	2,870	2,325
Jul.21	Am	Pm			
	7	5	1,443	575	466
	8	4	3,592	1,432	1,160
	9	3	5,418	2,160	1,750
	10	2	6,861	2,735	2,215
	11	1	7,715	3,075	2,491
	12	12	8,009	3,192	2,586
Aug.21	Am	Pm			
	7	5	1,434	572	463
	8	4	3,753	1,496	1,212
	9	3	5,798	2,311	1,872
	10	2	7,354	2,931	2,374
	11	1	8,300	3,308	2,679
	12	12	8,605	3,430	2,778

Hor. Irrad 2nd fl 10' fm. wind.

Sept.21	Am	Pm	Average Outdoor Horizontal Irradince (Foot Candle)	Final Daylight Factor (Df*dfwqg/dfgrass) 0.3986 (Foot Candle)	Transmittance Through Lo_E 0.81 (Foot Candle)
	7	5	1,207	481	390
	8	4	3,563	1,420	1,150
	9	3	5,683	2,265	1,835
	10	2	7,273	2,899	2,348
	11	1	8,245	3,286	2,662
	12	12	8,539	3,404	2,757
Oct.21	Am	Pm			
	7	5	1,019	406	329
	8	4	3,388	1,350	1,094
	9	3	5,576	2,223	1,801
	10	2	7,255	2,892	2,343
	11	1	8,305	3,310	2,681
	12	12	8,634	3,442	2,788
Nov.21	Am	Pm			
	7	5	779	311	252
	8	4	3,028	1,207	978
	9	3	5,187	2,068	1,675
	10	2	6,806	2,713	2,198
	11	1	7,825	3,119	2,526
	12	12	8,185	3,263	2,643
Dec.21	Am	Pm			
	7	5	671	267	216
	8	4	2,869	1,144	927
	9	3	5,066	2,019	1,635
	10	2	6,683	2,664	2,158
	11	1	7,721	3,078	2,493
	12	12	8,087	3,223	2,611

DAYLIGHT FACTOR : 15FT. FROM WINDOW

2ND. FLOOR

CEILING:
90% OF 2000 SQ. FT. = 1800 SQ. FT.
FLOOR :
50% OF 2000 SQ. FT. = 1000 SQ. FT.
VERTICAL WALLS :
90% OF 600 SQ. FT. = 540 SQ. FT.
GLASS WALL :
15% OF 1500 SQ. FT. = 225 SQ. FT.
TOTAL SurfaceAREA = Aceiling+Afloor+Awall+Aglass wall
= 2000+2000+600+1500 SQ. FT.
= 17500 SQ. FT.
AVERAGE REFLECTANCE FACTOR = 3565 SQ. FT./6100 SQ. FT.
= .58 OR 58%

Aimaginary window 1500 SQ. FT.
.... = ...
TOTAL SURFACE AREA 6100 SQ. FT.
= 0.25
SO, INTERNAL REFLECTANCE COMPONENT OF DAYLIGHT FACTOR
= 11.5%
SKY COMPONENT = 7.5%
EXTERNAL REFLECTED COMP'T. = 10% OF SKY COMPONENT
= .75%
DAYLIGHT FACTOR = 19.75%
$DF*DF_{\text{white quartz gravel}}/DF_{\text{grass}}$ (Final Daylight Factor) = 19.75*1.73
= 34.2%

Hor. Irrad 2nd fl 15' fm. wind.

Jan. 21	Am	Pm	Average Outdoor Horizontal Irradince (Foot Candle)	Final Daylight Factor (Df*dfwqg/dfgrass) 0.342 (Foot Candle)	Transmittance Through Lo_E 0.81 (Foot Candle)
	7	5	891	305	247
	8	4	3,495	1,195	968
	9	3	5,962	2,039	1,652
	10	2	7,846	2,683	2,173
	11	1	9,046	3,094	2,506
	12	12	9,423	3,223	2,611
Feb. 21	Am	Pm			
	7	5	1,201	411	333
	8	4	4,099	1,402	1,512
	9	3	6,749	2,308	1,869
	10	2	8,728	2,985	2,418
	11	1	9,999	3,420	2,770
	12	12	10,388	3,553	2,878
Mar. 21	Am	Pm			
	7	5	1,507	515	417
	8	4	4,520	1,546	1,252
	9	3	7,138	2,441	1,977
	10	2	9,183	3,141	2,544
	11	1	10,402	3,557	2,881
	12	12	10,761	3,680	2,981
Apr.21	Am	Pm			
	7	5	1,636	560	454
	8	4	4,385	1,500	1,215
	9	3	6,786	2,321	1,880
	10	2	8,631	2,952	2,391
	11	1	9,709	3,320	2,689
	12	12	10,057	3,439	2,786

Hor. Irrad 2nd fl 15' fm. wind.

May.21	Am	Pm	Average Outdoor Horizontal Irradince (Foot Candle)	Final Daylight Factor (Df*dfwqg/dfgrass) 0.342 (Foot Candle)	Transmittance Through Lo_E 0.81 (Foot Candle)
	7	5	1,606	549	445
	8	4	3,983	1,362	1,103
	9	3	5,878	2,010	1,628
	10	2	7,388	2,527	2,047
	11	1	8,577	2,933	2,376
	12	12	8,898	3,043	2,465
Jun.21	Am	Pm			
	7	5	1,338	458	371
	8	4	3,239	1,108	897
	9	3	4,899	1,675	1,357
	10	2	6,157	2,106	1,706
	11	1	6,960	2,380	1,928
	12	12	7,201	2,463	1,995
Jul.21	Am	Pm			
	7	5	1,443	494	400
	8	4	3,592	1,228	995
	9	3	5,418	1,853	1,501
	10	2	6,861	2,346	1,900
	11	1	7,715	2,639	2,138
	12	12	8,009	2,739	2,219
Aug.21	Am	Pm			
	7	5	1,434	490	397
	8	4	3,753	1,284	1,040
	9	3	5,798	1,983	1,606
	10	2	7,354	2,515	2,037
	11	1	8,300	2,839	2,300
	12	12	8,605	2,943	2,384

Hor. Irrad 2nd fl 15' fm. wind.

			Average Outdoor Horizontal Irradince	Final Daylight Factor (Df*dfwqg/dfgrass) 0.342	Transmittance Through Lo_E 0.81
Sept. 2	Am	Pm	(Foot Candle)	(Foot Candle)	(Foot Candle)
	7	5	1,207	413	335
	8	4	3,563	1,219	987
	9	3	5,683	1,944	1,575
	10	2	7,273	2,487	2,014
	11	1	8,245	2,820	2,284
	12	12	8,539	2,920	2,365
Oct.21	Am	Pm			
	7	5	1,019	348	282
	8	4	3,388	1,159	939
	9	3	5,576	1,907	1,545
	10	2	7,255	2,481	2,010
	11	1	8,305	2,840	2,300
	12	12	8,634	2,953	2,392
Nov.21	Am	Pm			
	7	5	779	266	215
	8	4	3,028	1,036	839
	9	3	5,187	1,774	1,437
	10	2	6,806	2,328	1,886
	11	1	7,825	2,676	2,168
	12	12	8,185	2,799	2,267
Dec.21	Am	Pm			
	7	5	671	229	185
	8	4	2,869	981	795
	9	3	5,066	1,733	1,404
	10	2	6,683	2,286	1,852
	11	1	7,721	2,641	2,139
	12	12	8,087	2,766	2,240

DAYLIGHT FACTOR : 20FT. FROM WINDOW

2ND. FLOOR

CEILING:

90% OF 2000 SQ. FT. = 1800 SQ. FT.

FLOOR :

50% OF 2000 SQ. FT. = 1000 SQ. FT.

VERTICAL WALLS :

90% OF 600 SQ. FT. = 540 SQ. FT.

GLASS WALL :

15% OF 1500 SQ. FT. = 225 SQ. FT.

TOTAL SurfaceAREA = Aceiling+Afloor+Awall+Aglass wall
= 2000+2000+600+1500 SQ. FT.
= 17500 SQ. FT.

AVERAGE REFLECTANCE FACTOR = 3565 SQ. FT./6100 SQ. FT.
= .58 OR 58%

Aimaginary window 1500 SQ. FT.
.... = ...
TOTAL SURFACE AREA 6100 SQ. FT.
= 0.25

SO, INTERNAL REFLECTANCE COMPONENT OF DAYLIGHT FACTOR
= 11.5%

SKY COMPONENT = 3.4%

EXTERNAL REFLECTED COMP'T. = 10% OF SKY COMPONENT
= .34%

DAYLIGHT FACTOR = 15.24%

$DF*DF_{\text{white quartz gravel}}/DF_{\text{grass}}$ (Final Daylight Factor) = 15.24*1.95
= 29.72%

Hor. Irrad 2nd fl 20' fm. wind.

			Average Outdoor Horizontal Irradince	Final Daylight Factor (Df*dfwqg/dfgrass) 0.297	Transmittance Through Lo_E 0.81
Jan. 21	Am	Pm	(Foot Candle)	(Foot Candle)	(Foot Candle)
	7	5	891	265	215
	8	4	3,495	1,038	841
	9	3	5,962	1,771	1,435
	10	2	7,846	2,330	1,887
	11	1	9,046	2,687	2,176
	12	12	9,423	2,799	2,267
Feb. 2	Am	Pm			
	7	5	1,201	357	289
	8	4	4,099	1,217	1,512
	9	3	6,749	2,004	1,623
	10	2	8,728	2,592	2,100
	11	1	9,999	2,970	2,406
	12	12	10,388	3,085	2,499
Mar. 2	Am	Pm			
	7	5	1,507	448	363
	8	4	4,520	2,084	1,688
	9	3	7,138	2,120	1,717
	10	2	9,183	2,727	2,209
	11	1	10,402	3,089	2,502
	12	12	10,761	3,196	2,589
Apr.21	Am	Pm			
	7	5	1,636	486	394
	8	4	4,385	1,302	1,055
	9	3	6,786	2,015	1,632
	10	2	8,631	2,563	2,076
	11	1	9,709	2,884	2,336
	12	12	10,057	2,987	2,419

Hor. Irrad 2nd fl 20' fm. wind.

May.2	Am	Pm	Average Outdoor Horizontal Irradince (Foot Candle)	Final Daylight Factor (Df*dfwqg/dfgrass) 0.297 (Foot Candle)	Transmittance Through Lo_E 0.81 (Foot Candle)
	7	5	1,606	477	386
	8	4	3,983	1,183	958
	9	3	5,878	1,746	1,414
	10	2	7,388	2,194	1,777
	11	1	8,577	2,547	2,063
	12	12	8,898	2,643	2,141
Jun.21	Am	Pm			
	7	5	1,338	397	322
	8	4	3,239	962	779
	9	3	4,899	1,455	1,179
	10	2	6,157	1,829	1,481
	11	1	6,960	2,067	1,674
	12	12	7,201	2,139	1,733
Jul.21	Am	Pm			
	7	5	1,443	429	347
	8	4	3,592	1,067	864
	9	3	5,418	1,609	1,303
	10	2	6,861	2,038	1,651
	11	1	7,715	2,291	1,856
	12	12	8,009	2,379	1,927
Aug.2	Am	Pm			
	7	5	1,434	426	345
	8	4	3,753	1,115	903
	9	3	5,798	1,722	1,395
	10	2	7,354	2,184	1,769
	11	1	8,300	2,465	1,997
	12	12	8,605	2,556	2,070

Hor. Irrad 2nd fl 20' fm. wind.

			Average Outdoor Horizontal Irradince (Foot Candle)	Final Daylight Factor (Df*dfwqg/dfgrass) 0.297 (Foot Candle)	Transmittance Through Lo_E 0.81 (Foot Candle)
Sept.2	Am	Pm			
	7	5	1,207	358	290
	8	4	3,563	1,058	857
	9	3	5,683	1,688	1,367
	10	2	7,273	2,160	1,750
	11	1	8,245	2,449	1,984
	12	12	8,539	2,536	2,054
Oct.21	Am	Pm			
	7	5	1,019	303	245
	8	4	3,388	1,006	815
	9	3	5,576	1,656	1,341
	10	2	7,255	2,155	1,746
	11	1	8,305	2,467	1,998
	12	12	8,634	2,564	2,077
Nov.2	Am	Pm			
	7	5	779	231	187
	8	4	3,028	899	728
	9	3	5,187	1,541	1,248
	10	2	6,806	2,021	1,637
	11	1	7,825	2,324	1,882
	12	12	8,185	2,431	1,969
Dec.21	Am	Pm			
	7	5	671	199	161
	8	4	2,869	852	690
	9	3	5,066	1,505	1,219
	10	2	6,683	1,985	1,608
	11	1	7,721	2,293	1,857
	12	12	8,087	2,402	1,946

2nd. fl. Top lighting 100'x20'

Jan. 21	Am	Pm	Average Outdoor Horizontal Irradince (Foot Candle)	Transmittance Through Lo_E 0.42 (Foot Candle)
	7	5	891	374
	8	4	3,495	1,468
	9	3	5,962	2,504
	10	2	9,046	3,799
	11	1	9,423	3,958
	12	12		
Feb. 21	Am	Pm		
	7	5	1,201	504
	8	4	4,099	1,890
	9	3	6,749	2,835
	10	2	8,728	3,666
	11	1	9,999	4,200
	12	12	10,388	4,363
Mar. 21	Am	Pm		
	7	5	1,507	633
	8	4	4,520	1,898
	9	3	7,138	2,998
	10	2	9,183	3,857
	11	1	10,402	4,369
	12	12	10,761	4,520
Apr.21	Am	Pm		
	7	5	1,636	687
	8	4	4,385	1,842
	9	3	6,786	2,850
	10	2	8,631	3,625
	11	1	9,709	4,078
	12	12	10,057	4,224

2nd. fl. Top lighting 100'x20'

	Am	Pm	Average Outdoor Horizontal Irradince (Foot Candle)	Transmittance Through Lo_E 0.42 (Foot Candle)
May.21	Am	Pm		
	7	5	1,606	675
	8	4	3,983	1,673
	9	3	5,878	2,469
	10	2	7,388	3,103
	11	1	8,577	3,602
	12	12	8,898	3,737
Jun.21	Am	Pm		
	7	5	1,338	562
	8	4	3,239	1,360
	9	3	4,899	2,058
	10	2	6,157	2,586
	11	1	6,960	2,923
	12	12	7,201	3,024
Jul.21	Am	Pm		
	7	5	1,443	606
	8	4	3,592	1,509
	9	3	5,418	2,276
	10	2	6,861	2,882
	11	1	7,715	3,240
	12	12	8,009	3,364
Aug.21	Am	Pm		
	7	5	1,434	602
	8	4	3,753	1,576
	9	3	5,798	2,435
	10	2	7,354	3,089
	11	1	8,300	3,486
	12	12	8,605	3,614

2nd. fl. Top lighting 100'x20'

Sept.21	Am	Pm	Average Outdoor Horizontal Irradince (Foot Candle)	Transmittance Through Lo_E 0.42 (Foot Candle)
	7	5	1,207	507
	8	4	3,563	1,496
	9	3	5,683	2,387
	10	2	7,273	3,055
	11	1	8,245	3,463
	12	12	8,539	3,586
Oct.21	Am	Pm		
	7	5	1,019	428
	8	4	3,388	1,423
	9	3	5,576	2,342
	10	2	7,255	3,047
	11	1	8,305	3,488
	12	12	8,634	3,626
Nov.21	Am	Pm		
	7	5	779	327
	8	4	3,028	1,272
	9	3	5,187	2,179
	10	2	6,806	2,859
	11	1	7,825	3,287
	12	12	8,185	3,438
Dec.21	Am	Pm		
	7	5	671	282
	8	4	2,869	1,205
	9	3	5,066	2,128
	10	2	6,683	2,807
	11	1	7,721	3,243
	12	12	8,087	3,397

APPENDIX 2 :

HEAT GAIN TRANSMITTED THROUGH THE Lo_E GLAZING

Gr. fl., north,Solar H't. Gain

	Am	Pm	NORTH Heat Gain Factor	Peak Heat Gain Th. Lo E glazing (S.C.=0.70) AT GR. FL. (25'x100'x0.70 x HGF)+(25'x100'x.70x.25 of HGF) BTUH
Jan. 21	7	5	8	
	8	4	17	
	9	3	23	
	10	2	28	
	11	1	31	67813
	12	12	32	
Feb. 21	Am	Pm		
	7	5	9	
	8	4	18	
	9	3	25	
	10	2	30	
	11	1	33	72188
	12	12	34	
Mar. 21	Am	Pm		
	7	5	12	
	8	4	21	
	9	3	28	
	10	2	33	
	11	1	36	78750
	12	12	37	
Apr.21	Am	Pm		
	7	5	28	
	8	4	36	
	9	3	39	
	10	2	42	
	11	1	43	94063
	12	12	44	

Gr. fl., north,Solar H't. Gain

	Am	Pm	NORTH Heat Gain Factor	Peak Heat Gain Th. Lo E glazing (S.C.=0.70) AT GR. FL. (25'x100'x0.70 x HGF)+(25'x100'x.70x.25 of HGF) BTUH
May.21	Am	Pm		
	7	5	54	
	8	4	68	
	9	3	72	
	10	2	73	159688
	11	1	74	
	12	12	74	
Jun.21	Am	Pm		
	7	5	64	
	8	4	82	
	9	3	88	192500
	10	2	90	
	11	1	90	
	12	12	90	
Jul.21	Am	Pm		
	7	5	54	
	8	4	70	
	9	3	75	
	10	2	76	166250
	11	1	77	
	12	12	77	
Aug.21	Am	Pm		
	7	5	30	
	8	4	39	
	9	3	43	
	10	2	45	98438
	11	1	47	
	12	12	47	

Gr. fl., north,Solar H't. Gain

			NORTH Heat Gain Factor	Peak Heat Gain Th. Lo E glazing (S.C.=0.70) AT GR. FL. (25'x100'x0.70 x HGF)+(25'x100'x.70x.25 of HGF) BTUH
Sep.21	Am	Pm		
	7	5	13	
	8	4	22	
	9	3	29	
	10	2	34	
	11	1	37	80938
	12	12	38	
Oct.21	Am	Pm		
	7	5	10	
	8	4	19	
	9	3	26	
	10	2	31	67813
	11	1	34	
	12	12	34	
Nov.21	Am	Pm		
	7	5	8	
	8	4	17	
	9	3	24	
	10	2	29	
	11	1	32	70000
	12	12	33	
Dec.21	Am	Pm		
	7	5	7	
	8	4	16	
	9	3	22	
	10	2	27	
	11	1	30	65625
	12	12	31	

Gr. fl., south,Solar H't. Gain

			SOUTH Heat Gain Factor	Peak Heat Gain Th. Lo E glazing (S.C.=0.70) AT GR. FL. (25'x100'x0.70xHGF)+(25'x100'x0.70x.25 of HGF) BTUH
Jan. 21	Am	Pm		
	7	5	61	
	8	4	105	
	9	3	131	
	10	2	149	
	11	1	159	347813
	12	12	162	
Feb. 21	Am	Pm		
	7	5	35	
	8	4	63	
	9	3	83	
	10	2	98	
	11	1	107	234063
	12	12	110	
Mar. 21	Am	Pm		
	7	5	13	
	8	4	25	
	9	3	37	
	10	2	47	
	11	1	53	115938
	12	12	55	
Apr.21	Am	Pm		
	7	5	13	
	8	4	23	
	9	3	30	
	10	2	35	
	11	1	38	83125
	12	12	39	

Gr. fl., south,Solar H't. Gain

			SOUTH Heat Gain Factor	Peak Heat Gain Th. Lo E glazing (S.C.=0.70) AT GR. FL. (25'x100'x0.70xHGF)+(25'x100'x0.70x.25 of HGF) BTUH
May.21	Am	Pm		
	7	5	14	
	8	4	23	
	9	3	30	
	10	2	34	
	11	1	37	80938
	12	12	38	
Jun.21	Am	Pm		
	7	5	14	
	8	4	23	
	9	3	30	
	10	2	35	
	11	1	38	83125
	12	12	39	
Jul.21	Am	Pm		
	7	5	14	
	8	4	24	
	9	3	30	
	10	2	35	
	11	1	38	83125
	12	12	39	
Aug.21	Am	Pm		
	7	5	14	
	8	4	24	
	9	3	31	
	10	2	37	
	11	1	40	87500
	12	12	41	

Gr. fl., south,Solar H't. Gain

Sep.21	Am	Pm	SOUTH Heat Gain Factor	Peak Heat Gain Th. Lo E glazing (S.C.=0.70) AT GR. FL. (25'x100'x0.70xHGF)+(25'x100'x0.70x.25 of HGF) BTUH
	7	5	14	
	8	4	27	
	9	3	38	
	10	2	48	
	11	1	54	118125
	12	12	56	
Oct.21	Am	Pm		
	7	5	33	
	8	4	60	
	9	3	80	
	10	2	95	
	11	1	105	229688
	12	12	108	
Nov.21	Am	Pm		
	7	5	59	
	8	4	103	
	9	3	129	
	10	2	146	
	11	1	157	343438
	12	12	160	
Dec.21	Am	Pm		
	7	5	68	
	8	4	120	
	9	3	147	
	10	2	165	
	11	1	176	385000
	12	12	179	

Gr. FL., total Peak Solar H't.

MONTHS	Total Peak H.G. Th. Lo E glazing (S.C.=0.70) AT GR. FL. BTUH
Jan. 21	415626
Feb. 21	306251
Mar. 21	194688
Apr.21	177188
May.21	240626
Jun.21	275625
Jul.21	249375
Aug.21	185938
Sep.21	199063
Oct.21	297501
Nov.21	413438
Dec.21	450625

1st fl., north,Solar H't. Gain

			NORTH Heat Gain Factor	Peak Heat Gain Th. Lo E glazing (S.C.=0.70)AT FIRST FL. (20'x100'x0.70 x HGF)+(20'x100'x0.70x.25xHGF) BTUH
Jan. 21	Am	Pm		
	7	5	8	
	8	4	17	
	9	3	23	
	10	2	28	
	11	1	31	54250
	12	12	32	
Feb. 21	Am	Pm		
	7	5	9	
	8	4	18	
	9	3	25	
	10	2	30	
	11	1	33	57750
	12	12	34	
Mar. 21	Am	Pm		
	7	5	12	
	8	4	21	
	9	3	28	
	10	2	33	
	11	1	36	63000
	12	12	37	
Apr.21	Am	Pm		
	7	5	28	
	8	4	36	
	9	3	39	
	10	2	42	
	11	1	43	75250
	12	12	44	

1st fl., north,Solar H't. Gain

			NORTH Heat Gain Factor	Peak Heat Gain Th. Lo E glazing (S.C.=0.70)AT FIRST FL. (20'x100'x0.70 x HGF)+(20'x100'x0.70x.25xHGF) BTUH
May.21	Am	Pm		
	7	5	54	
	8	4	68	
	9	3	72	
	10	2	73	127750
	11	1	74	
	12	12	74	
Jun.21	Am	Pm		
	7	5	64	
	8	4	82	
	9	3	88	154000
	10	2	90	
	11	1	90	
	12	12	90	
Jul.21	Am	Pm		
	7	5	54	
	8	4	70	
	9	3	75	
	10	2	76	133000
	11	1	77	
	12	12	77	
Aug.21	Am	Pm		
	7	5	30	
	8	4	39	
	9	3	43	
	10	2	45	78750
	11	1	47	
	12	12	47	

1st fl., north,Solar H't. Gain

Sep.21	Am	Pm	NORTH Heat Gain Factor	Peak Heat Gain Th. Lo E glazing (S.C.=0.70)AT FIRST FL. (20'x100'x0.70 x HGF)+(20'x100'x0.70x.25xHGF) BTUH
	7	5	13	
	8	4	22	
	9	3	29	
	10	2	34	
	11	1	37	64750
	12	12	38	
Oct.21	Am	Pm		
	7	5	10	
	8	4	19	
	9	3	26	
	10	2	31	54250
	11	1	34	
	12	12	34	
Nov.21	Am	Pm		
	7	5	8	
	8	4	17	
	9	3	24	
	10	2	29	
	11	1	32	56000
	12	12	33	
Dec.21	Am	Pm		
	7	5	7	
	8	4	16	
	9	3	22	
	10	2	27	
	11	1	30	52500
	12	12	31	

1st fl., south,Solar H't. Gain

Jan. 21	Am	Pm	SOUTH Heat Gain Factor	Peak Heat Gain Th. Lo E glazing (S.C.=0.70)AT FIRST FL. (20'x100'x0.70 x HGF)+(20'x100'x0.70x.25xHGF) BTUH
	7	5	61	
	8	4	105	
	9	3	131	
	10	2	149	
	11	1	159	278250
	12	12	162	
Feb. 21	Am	Pm		
	7	5	35	
	8	4	63	
	9	3	83	
	10	2	98	
	11	1	107	187250
	12	12	110	
Mar. 21	Am	Pm		
	7	5	13	
	8	4	25	
	9	3	37	
	10	2	47	
	11	1	53	92750
	12	12	55	
Apr.21	Am	Pm		
	7	5	13	
	8	4	23	
	9	3	30	
	10	2	35	
	11	1	38	66500
	12	12	39	

1st fl., south,Solar H't. Gain

May.21	Am	Pm	SOUTH Heat Gain Factor	Peak Heat Gain Th. Lo E glazing (S.C.=0.70)AT FIRST FL. (20'x100'x0.70 x HGF)+(20'x100'x0.70x.25xHGF) BTUH
	7	5	14	
	8	4	23	
	9	3	30	
	10	2	34	
	11	1	37	64750
	12	12	38	
Jun.21	Am	Pm		
	7	5	14	
	8	4	23	
	9	3	30	
	10	2	35	
	11	1	38	66500
	12	12	39	
Jul.21	Am	Pm		
	7	5	14	
	8	4	24	
	9	3	30	
	10	2	35	
	11	1	38	66500
	12	12	39	
Aug.21	Am	Pm		
	7	5	14	
	8	4	24	
	9	3	31	
	10	2	37	
	11	1	40	70000
	12	12	41	

1st fl., south,Solar H't. Gain

Sep.21	Am	Pm	SOUTH Heat Gain Factor	Peak Heat Gain Th. Lo E glazing (S.C.=0.70)AT FIRST FL. (20'x100'x0.70 x HGF)+(20'x100'x0.70x.25xHGF) BTUH
	7	5	14	
	8	4	27	
	9	3	38	
	10	2	48	
	11	1	54	94500
	12	12	56	
Oct.21	Am	Pm		
	7	5	33	
	8	4	60	
	9	3	80	
	10	2	95	
	11	1	105	183750
	12	12	108	
Nov.21	Am	Pm		
	7	5	59	
	8	4	103	
	9	3	129	
	10	2	146	
	11	1	157	274750
	12	12	160	
Dec.21	Am	Pm		
	7	5	68	
	8	4	120	
	9	3	147	
	10	2	165	
	11	1	176	308000
	12	12	179	

1st. FL., Total Peak Solar H't.

MONTHS	Total Peak H.G. Th. Lo E glazing (S.C.=0.70) AT 1st. FL. BTUH
Jan. 21	332500
Feb. 21	245000
Mar. 21	155750
Apr.21	141750
May.21	192500
Jun.21	220500
Jul.21	199500
Aug.21	148750
Sep.21	159250
Oct.21	238000
Nov.21	330750
Dec.21	360500

2nd. fl. North, Solar Heat Gain

			NORTH Heat Gain Factor	Peak Heat Gain Th. Lo E glazing (S.C.=0.37)AT 2ND. FL. (15'x100'x0.37 x HGF)+(15'x100'x0.37x.25 of HGF) BTUH
Jan. 21	Am	Pm		
	7	5	8	
	8	4	17	
	9	3	23	
	10	2	28	
	11	1	31	21506.25
	12	12	32	
Feb. 21	Am	Pm		
	7	5	9	
	8	4	18	
	9	3	25	
	10	2	30	
	11	1	33	22893.75
	12	12	34	
Mar. 21	Am	Pm		
	7	5	12	
	8	4	21	
	9	3	28	
	10	2	33	
	11	1	36	24975
	12	12	37	
Apr.21	Am	Pm		
	7	5	28	
	8	4	36	
	9	3	39	
	10	2	42	
	11	1	43	29831.25
	12	12	44	

2nd. fl. North, Solar Heat Gain

			NORTH Heat Gain Factor	Peak Heat Gain Th. Lo E glazing (S.C.=0.37)AT 2ND. FL. (15'x100'x0.37 x HGF)+(15'x100'x0.37x.25 of HGF) BTUH
May.21	Am	Pm		
	7	5	54	
	8	4	68	
	9	3	72	
	10	2	73	50643.75
	11	1	74	
	12	12	74	
Jun.21	Am	Pm		
	7	5	64	
	8	4	82	
	9	3	88	61050
	10	2	90	
	11	1	90	
	12	12	90	
Jul.21	Am	Pm		
	7	5	54	
	8	4	70	
	9	3	75	
	10	2	76	52725
	11	1	77	
	12	12	77	
Aug.21	Am	Pm		
	7	5	30	
	8	4	39	
	9	3	43	
	10	2	45	31218.75
	11	1	47	
	12	12	47	

2nd. fl. North, Solar Heat Gain

			NORTH Heat Gain Factor	Peak Heat Gain Th. Lo E glazing (S.C.=0.37)AT 2ND. FL. (15'x100'x0.37 x HGF)+(15'x100'x0.37x.25 of HGF) BTUH
Sep.21	Am	Pm		
	7	5	13	
	8	4	22	
	9	3	29	
	10	2	34	
	11	1	37	25668.75
	12	12	38	
Oct.21	Am	Pm		
	7	5	10	
	8	4	19	
	9	3	26	
	10	2	31	21506.25
	11	1	34	
	12	12	34	
Nov.21	Am	Pm		
	7	5	8	
	8	4	17	
	9	3	24	
	10	2	29	
	11	1	32	22200
	12	12	33	
Dec.21	Am	Pm		
	7	5	7	
	8	4	16	
	9	3	22	
	10	2	27	
	11	1	30	20812.5
	12	12	31	

2ND. fl. South, Solar Heat Gain

			SOUTH Heat Gain Factor	Peak Heat Gain Th. Lo E glazing (S.C.=0.37) AT 2ND. FL. (15'x100'x0.37 x HGF)+(15'x100'x0.37x.25 of HGF) BTUH
Jan. 21	Am	Pm		
	7	5	61	
	8	4	105	
	9	3	131	
	10	2	149	
	11	1	159	110306.25
	12	12	162	
Feb. 21	Am	Pm		
	7	5	35	
	8	4	63	
	9	3	83	
	10	2	98	
	11	1	107	74231.25
	12	12	110	
Mar. 21	Am	Pm		
	7	5	13	
	8	4	25	
	9	3	37	
	10	2	47	
	11	1	53	36768.75
	12	12	55	
Apr.21	Am	Pm		
	7	5	13	
	8	4	23	
	9	3	30	
	10	2	35	
	11	1	38	26362.5
	12	12	39	

2ND. fl. South, Solar Heat Gain

			SOUTH Heat Gain Factor	Peak Heat Gain Th. Lo E glazing (S.C.=0.37) AT 2ND. FL. (15'x100'x0.37 x HGF)+(15'x100'x0.37x.25 of HGF) BTUH
May.21	Am	Pm		
	7	5	14	
	8	4	23	
	9	3	30	
	10	2	34	
	11	1	37	25668.75
	12	12	38	
Jun.21	Am	Pm		
	7	5	14	
	8	4	23	
	9	3	30	
	10	2	35	
	11	1	38	26362.5
	12	12	39	
Jul.21	Am	Pm		
	7	5	14	
	8	4	24	
	9	3	30	
	10	2	35	
	11	1	38	26362.5
Aug.21	Am	Pm		
	7	5	14	
	8	4	24	
	9	3	31	
	10	2	37	
	11	1	40	27750
	12	12	41	

2ND. fl. South, Solar Heat Gain

	Am	Pm	SOUTH Heat Gain Factor	Peak Heat Gain Th. Lo E glazing (S.C.=0.37) AT 2ND. FL. (15'x100'x0.37 x HGF)+(15'x100'x0.37x.25 of HGF) BTUH
Sep.21				
	7	5	14	
	8	4	27	
	9	3	38	
	10	2	48	
	11	1	54	37462.5
	12	12	56	
Oct.21	Am	Pm		
	7	5	33	
	8	4	60	
	9	3	80	
	10	2	95	
	11	1	105	72843.75
	12	12	108	
Nov.21	Am	Pm		
	7	5	59	
	8	4	103	
	9	3	129	
	10	2	146	
	11	1	157	108918.75
	12	12	160	
Dec.21	Am	Pm		
	7	5	68	
	8	4	120	
	9	3	147	
	10	2	165	
	11	1	176	122100
	12	12	179	

2nd. fl.horiz'l Solar H't. Gai

			HORIZONTAL	Peak Heat Gain Th. Lo E glazing (S.C.=0.37)AT 2ND. FL.
Jan. 21	Am	Pm	Heat Gain Factor	(20 ft x 100 ft) x 0.37 x HGF
	7	5	26	BTUH
	8	4	102	
	9	3	174	
	10	2	229	
	11	1	264	195360
	12	12	275	
Feb. 21	Am	Pm		
	7	5	34	
	8	4	116	
	9	3	191	
	10	2	247	
	11	1	283	209420
	12	12	294	
Mar. 21	Am	Pm		
	7	5	42	
	8	4	126	
	9	3	199	
	10	2	256	
	11	1	290	214600
	12	12	300	
Apr.21	Am	Pm		
	7	5	47	
	8	4	126	
	9	3	195	
	10	2	248	
	11	1	279	206460
	12	12	289	

2nd. fl.horiz'l Solar H't. Gai

			HORIZONTAL	Peak Heat Gain Th. Lo E glazing (S.C.=0.37)AT 2ND. FL.
May.21	Am	Pm	Heat Gain Factor	(20 ft x 100 ft) x 0.37 x HGF
	7	5	50	
	8	4	124	
	9	3	188	
	10	2	237	
	11	1	267	197580
	12	12	277	
Jun.21	Am	Pm		
	7	5	50	
	8	4	121	
	9	3	183	
	10	2	230	
	11	1	260	192400
	12	12	269	
Jul.21	Am	Pm		
	7	5	49	
	8	4	122	
	9	3	184	
	10	2	233	
	11	1	262	193880
	12	12	272	
Aug.21	Am	Pm		
	7	5	47	
	8	4	123	
	9	3	190	
	10	2	241	
	11	1	272	201280
	12	12	282	

2nd. fl.horiz'l Solar H't. Gai

			HORIZONTAL	Peak Heat Gain Th. Lo E glazing (S.C.=0.37)AT 2ND. FL.
Sep.21	Am	Pm	Heat Gain Factor	(20 ft x 100 ft) x 0.37 x HGF
	7	5	41	
	8	4	121	
	9	3	193	
	10	2	247	
	11	1	280	207200
	12	12	290	
Oct.21	Am	Pm		
	7	5	34	
	8	4	113	
	9	3	186	
	10	2	242	
	11	1	277	204980
	12	12	288	
Nov.21	Am	Pm		
	7	5	26	
	8	4	101	
	9	3	173	
	10	2	227	
	11	1	261	193140
	12	12	273	
Dec.21	Am	Pm		
	7	5	22	
	8	4	94	
	9	3	166	
	10	2	219	
	11	1	253	187220
	12	12	265	

70,.37, 2nd. FL., Total Peak

MONTHS	Peak Heat Gain Th. Lo E glazing (S.C.=0.37, 0.70) AT 2ND. FL. BTUH
Jan. 21	444,735.00
Feb. 21	393,170.00
Mar. 21	331,412.50
Apr.21	312,772.50
May.21	341,955.00
Jun.21	357,775.00
Jul.21	343,505.00
Aug.21	312,842.50
Sep.21	326,637.50
Oct.21	383,480.00
Nov.21	441,202.50
Dec.21	457,595.00

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