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STUDY OF THE APPLICATION OF SOLAR CHEMICAL DEHUMIDIFICATION SYSTEM
TO
WIND TUNNEL FACILITIES OF NASA LEWIS RESEARCH CENTER
AT
CLEVELAND, OHIO

NASA CONTRACT NO. NASW-2920

(NASA-CR-149886) STUDY OF THE APPLICATION OF SOLAR CHEMICAL DEHUMIDIFICATION SYSTEM TO WIND TUNNEL FACILITIES OF NASA LEWIS RESEARCH CENTER AT CLEVELAND, OHIO (Meckler (Gershon) Associates, Washington, D. C.)
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EXECUTIVE SUMMARY

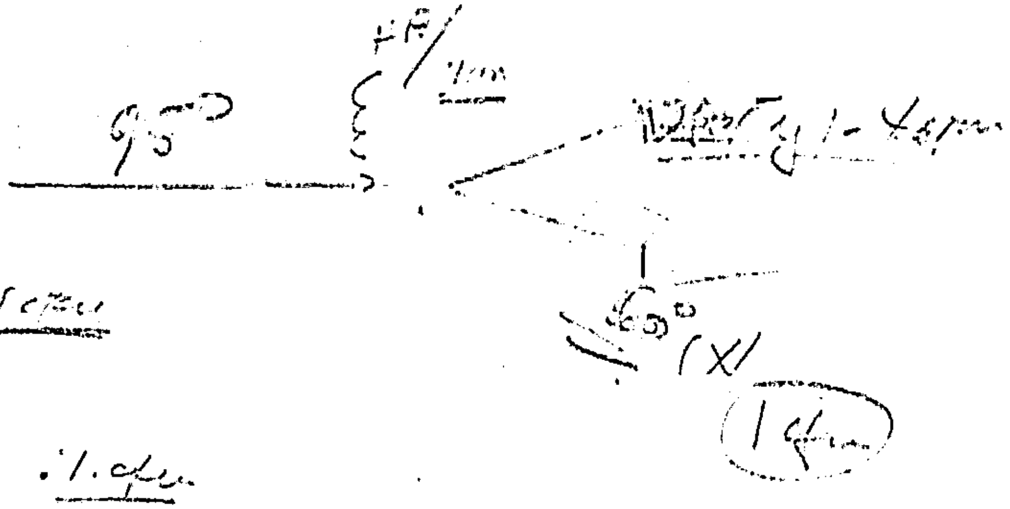
A. INTRODUCTION

Gershon Meckler Associates, P.C., has prepared this report to assess the feasibility of using a solar chemical dehumidification system to reduce the energy utilized to dehumidify the air supplied to the wind tunnels at the Lewis Research Center (LeRC), Cleveland, Ohio. This report documents the results of evaluation of proposed modifications to the 8' x 6' and 10' x 10' wind tunnels at LeRC.

The wind tunnels are designed to operate on either an aerodynamic cycle or a propulsion cycle. During the aerodynamic cycle the tunnel is operated as a closed system with dry air added only as required to maintain the desired tunnel conditions. This cycle is used primarily for aerodynamic flow studies where contaminants are not introduced into the airstream. During the propulsion cycle the tunnel is operated as an open system with the outside air continuously drawn through the air dryer and exhausted to the atmosphere. This cycle is used for models which introduce contaminants into the airstream.

Energy utilization and cost payback analyses have been prepared for the following proposed modifications:

1. The addition of a 50,000 CFM standard compact packaged solid desiccant dehumidifier utilizing high temperature hot water (HTHW) for desiccant regeneration. The HTHW is generated by utilizing solar energy and is stored in a storage tank. A steam boiler is provided as a back-up for the solar system.
2. The addition of a 50,000 CFM standard compact package solid desiccant dehumidifier utilizing high temperature hot water (HTHW) for desiccant regeneration. The HTHW is generated by utilizing a steam boiler and a heat exchanger and is stored in a storage tank.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3. The use of air to air heat exchangers for recovering the waste heat in the reactivation cycles.

4. During the aerodynamic cycle operation when only 50,000 CFM is required, the outside air intake dampers will be closed completely in the 8' x 6' and the 10' x 10' wind tunnel dryer buildings. Providing a small opening (100 sq.ft.) in the outside air intake dampers will reduce moisture migration thereby reducing saturation of the desiccant beds.

B. BASES OF ANALYSIS

Energy utilization and cost payback analyses of the 8' x 6' and 10' x 10' wind tunnels are based on:

1. The wind tunnels operate 90% of operating time in aerodynamic cycle mode and 10% of operating time in the propulsion cycle mode.

2. The number of annual duty cycles are as follows:

Wind Tunnel	Aerodynamic Cycle	Propulsion Cycle
8' x 6'	76	8
10' x 10'	56	6

3. Cost of gas: $2.40/1000 cu.ft.

4. The investment cost and payback period calculated according to NASA's Calculations of "Pay Back" for Direct Energy Projects. Directive dated July 7, 1976.

C. EVALUATION OF THE PROPOSED MODIFICATIONS

The results of evaluation of the proposed modifications are given in the following table.

PROPOSED MODIFICATION NO.	INITIAL INVESTMENT		TOTAL YEARLY SAVING		SIMPLE PAYBACK WITHOUT ESCALATION		SIMPLE PAYBACK WITH ESCALATION	
	8'x6'	10'x10'	8'x6'	10'x10'	8'x6'	10'x10'	8'x6'	10'x10'
	$		$		Years		Years	
1	356,400		28,334	35,486	11.3	8.79	7.79	6.45
2	279,400		25,583	33,457	10.92	8.3	7.09	5.4
3	[illegible]76,800	336,000	17,400	12,202	13.5	18.4	--	--
4	15,000	15,000	3,438	4,501	4.36	3.33	--	--

D. RECOMMENDATIONS

After analyzing the investment cost, energy savings and payback periods of the various proposed modification options, we recommend the following modification be made to the 8' x 6' and 10' x 10' wind tunnels.

1. The addition of a 50,000 CFM solid desiccant solar chemical dehumidifier to each wind tunnel to be arranged to operate during the Aerodynamic cycles.
2. Providing a small opening (100 sq. ft.) in the outside air intake dampers of the 8' x 6' and 10' x 10' dryer building will increase the number of aerodynamic cycles that can be achieved before desiccant reactivation is required.

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Energy utilization and cost payback analyses have been performed for the following proposed systems:

1. The addition of a 50,000 CFM standard compact packaged solid desiccant dehumidifier utilizing high temperature hot water (HTHW) for desiccant regeneration. The HTHW is generated by utilizing solar energy and is stored in a storage tank. A steam boiler is provided as a back-up for the solar system.
2. The addition of a 50,000 CFM standard compact package solid desiccant dehumidifier utilizing high temperature hot water (HTHW) for desiccant regeneration. The HTHW is generated by utilizing a steam boiler and a heat exchanger and is stored in a storage tank.
3. The use of air to air heat exchangers for recovering the waste heat in the reactivation cycles.
4. During aerodynamic cycle operation when only 50,000 CFM is required, the outside air intake dampers will be closed completely in the 8' x 6' and the 10' x 10' wind tunnel dryer buildings. Providing only a small opening (100 sq.ft.) in the outside air intake dampers will reduce moisture migration which accelerates the saturation of the desiccant beds.

B. EXISTING WIND TUNNEL SYSTEMS

1. Major Components of the 8' x 6' and 10' x 10' Wind Tunnels

Air dryer - The air dryer removes moisture from atmospheric air prior to its introduction into the tunnel. It contains activated alumina in beds. The dryer is designed for dry CFM air for a two hour period. The air enters at 21°C (70°F) with a dewpoint of 14°C (58°F) and leaves with a dewpoint of -40°F.

Compressor - The tunnel air is driven by an axial-flow compressor. It is driven by three wound-rotor induction motors.

Flexible-wall nozzle - The flexible-wall nozzle produces supersonic flow through the test section; it consists of two flexible one inch thick stainless steel side units which are actuated by hydraulically operated screwjacks. The top and bottom plates are fixed.

Acoustic muffler - The acoustic muffler is used to quiet the discharge air of the tunnel when it is operated on either the aerodynamic or the propulsion cycle.

Cooler - The cooler is a finned-tube water type heat exchanger, used to cool the air entering the air dryer by removing the heat of compression.

2. Existing Wind Tunnels Operation

The wind tunnels can be operated through the Mach number ranges of 2 to 3.5 on either an aerodynamic cycle or a propulsion cycle. During the aerodynamic cycle, the tunnel operates as a closed return-type tunnel and on the propulsion cycle it operates as an open nonreturn-type tunnel.

The Air Dryer Building provides filtered and dried air for the tunnel. During the operation of the wind tunnel the air dryer will be set for either the "air drying", "by-pass" or "standby" cycle. Atmospheric air will be drawn by the tunnel compressors through moisture adsorptive beds where the dewpoint of the air will be approximately -40°F or lower before it passes through the secondary filter band to the tunnel inlet. As required, effluent dewpoint of air is extremely low it is imperative that the building be maintained as nearly airtight as possible to prevent any air from entering the tunnel during the air drying cycle that has not passed through the beds. To reactivate the beds after they have become saturated with the moisture removed from the air, they will be heated to approximately 350°F and then cooled to as low a temperature as practical using available cooling-tower water and the dry heat exchanger coils. The reactivation of the dryer which includes both heating and cooling cycles is accomplished in approximately 8 hours with 4 hours allowed for each cycle. Heating is accomplished by forcing the products of combustion of natural gas and filtered air mixed with the proper quantities of filtered secondary air to provide the desired temperature of 350°F for the resultant mixture. This mixture is forced through the beds in the reverse direction compared with the direction of air flow during the air drying cycle. The re-evaporated moisture together with combustion products are discharged to the atmosphere through the roof dampers. The cooling of the beds is achieved by continuously circulating the air contained within the building through cooling coils into the beds in the direction used during the air drying cycle. Circulation for both the heating and cooling cycles is achieved by means of blowers located within the building.

Provision has been made to operate the dryer on "air drying", "by-pass" and "standby" cycles from the main tunnel control room. When the control switch on the air dryer panel is set to "Remote" and control has been accepted by the tunnel control room operator, as indicated by the green light on the air dryer panel, then the tunnel control room operator can set up any of the above 3 cycles at will without the assistance of the air dryer personnel. The absorptive beds are housed in an all-steel structure with an air-tight steel skin welded to the outside of external framing members. The structure is designed to withstand temperature changes between 0 (zero) degrees Fahrenheit and 400 (four hundred) degrees Fahrenheit, internal pressures varying from 15 (fifteen) inches of water below to 10 (ten) inches of water above ambient atmospheric pressure, and any combination of pressure and temperature within these limits in addition to normal building design loads such as dead weight, live load, aerodynamic loads, wind and snow loadings.

Under all conditions the bed-area housing and all directly connected plenum areas, as well as the reactivation-equipment room, are intended to be air-tight.

Schematic flow diagrams of 8' x 6' and 10' x 10' wind tunnels are given in Figures 1 and 2 respectively.

C. BASES OF ANALYSIS

1. Energy utilization and cost payback analyses of the 8' x 6' and 10' x 10' wind tunnels are based on:

*1) The wind tunnels operate 90% of the operating time in the aerodynamic cycle mode and 10% of operating time in the propulsion cycle mode.

*2) The number of annual duty cycles are as follows:

Wind Tunnel	Aerodynamic Cycle	Propulsion Cycle
8' x 6'	76	8
10' x 10'	56	6

*3) Cost of gas: $2.40/1000 cu.ft.

4) Investment cost and payback period, calculated according to NASA's Calculations of "Pay Back" for Direct Energy Projects directive dated July 7, 1976.

D. WIND TUNNEL DATA

In this study the wind tunnel data below has served as a basis for the analysis.

		8' x 6'	10' x 10'
Mass flow rate, lbs./sec.		2,200	1,838
Inlet conditions	(Dry bulb temp., °F	85	85
	(Wet bulb temp., °F	73	73
	(Dew point temp., °F	67	67
	(Relative humidity, %	58	58
Grains water to be removed per lb. of dry air		103	103
Mass of alumina, lb		2,300,000	3,780,000
Adsorption per lb., %		5.4	3.33
Total water adsorption capacity, lb.		124,000	125,900

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* Items 1 thru 3 have been obtained from Mr. Raymond J. Karabinus, Research Engineer, Lewis Research Center, Cleveland, Ohio.

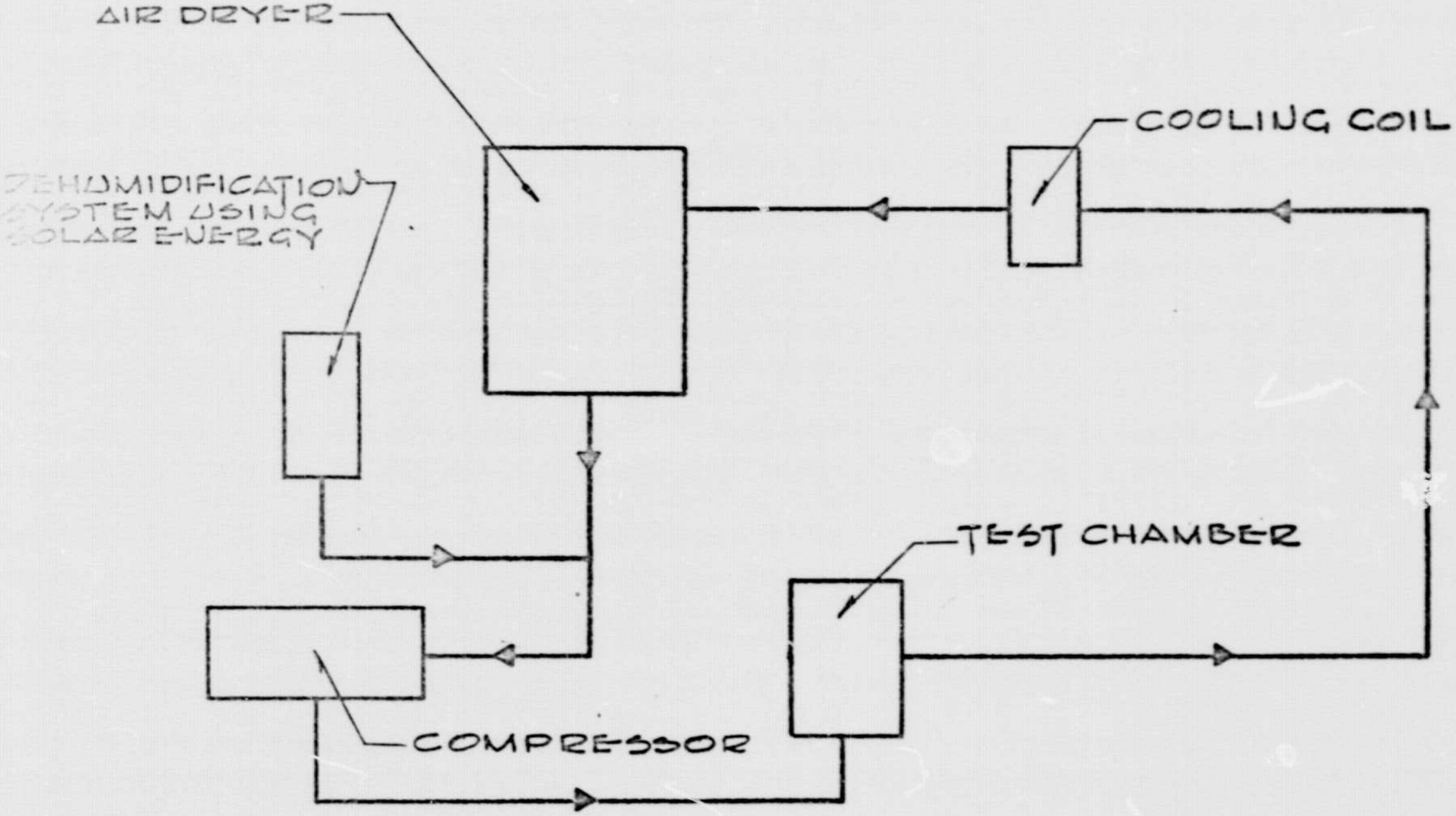

FIGURE 1 SCHEMATIC FLOW DIAGRAM 8'X 6' TUNNEL

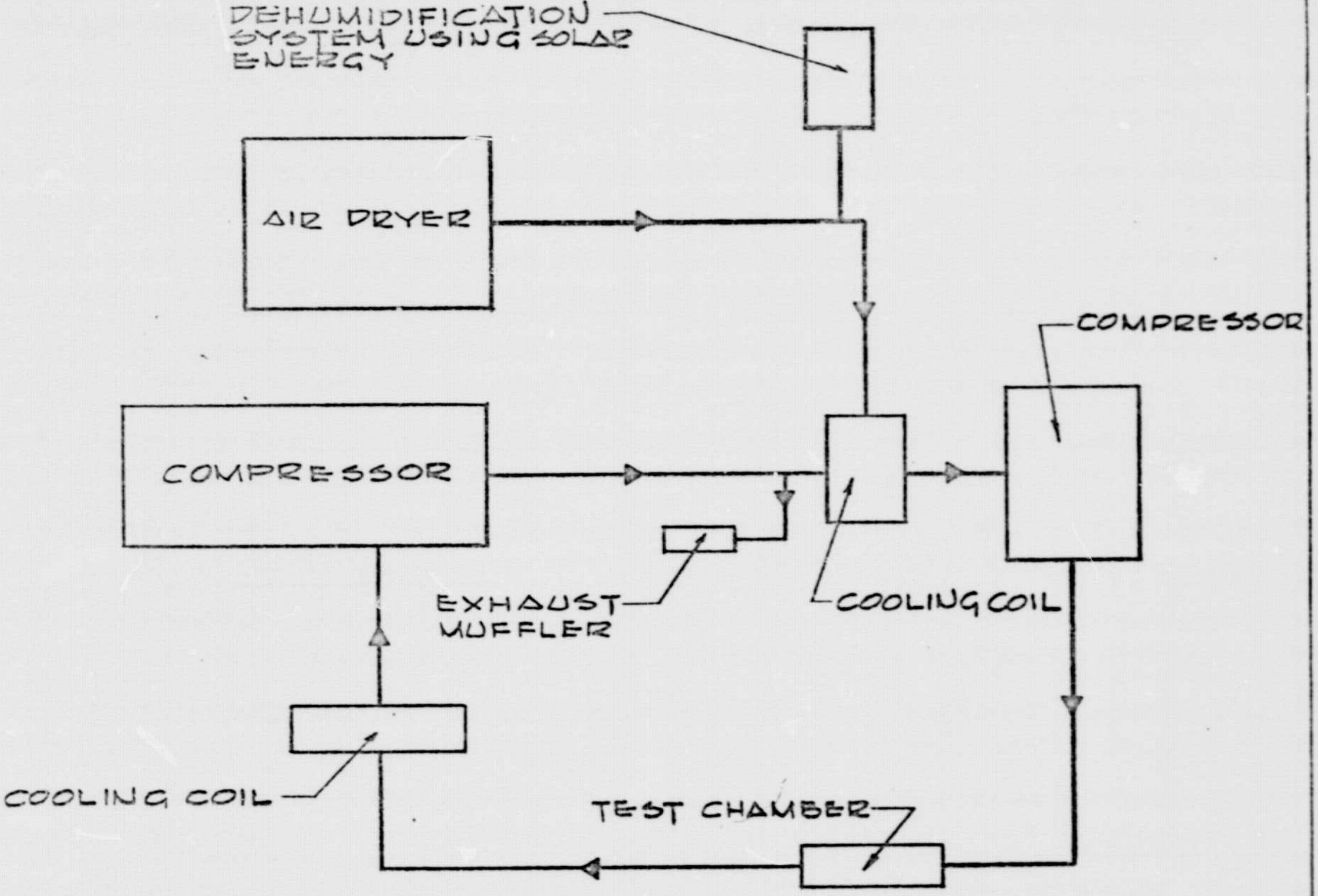

FIGURE 2 SCHEMATIC FLOW· DIAGRAM 10'X10' TUNNEL

	8' x 6'	10' x 10'
Bed Area, Sq.ft.	23,520	25,200
Bed thickness, inches	24	32
Face velocity, feet per minute	75	60
Pressure drop through beds, inches of water	4.7	4.0
Pressure drop through building, inches of water	7.8	6.0

- Reactivation Equipment
  - Heaters

	8' x 6'	10' x 10'
Number of units	20	30
Btu per unit per hr	8,000,000	8,000,000
Total Btu/per hr	160,000,000	240,000,000
Combustion air pressure, oz.	16	12
Combustion air blower HP	275	200
Fuel/air ratio - approx.	12.5:1	14:2

- Coolers

	8' x 6'	10' x 10'
Number of units	52	36
Total face area sq.ft.	1,172	1,080
Maximum water rate, g.p.m.	10,000	9,330
Water pressure drop, feet head	90	60
Air pressure drop, inches water	1.4	1.6
Max. Temperature rise, water, °F.	70	65
Max. Temperature drop, air, °F.	250	250

- Fans

	8' x 6'	10' x 10'
Number of units	8	8
HP per unit	125	125
Total HP	1,000	1,600
Scfm flow forward (cooling)	600,000	835,000
Pressure rise forward, inches water	6.0	6.7
Max.(no flow) pressure rise, inches water	--	8.9
Scfm flow reverse (heating)	420,000	721.000
Press, rise reverse inches water	3.9	5.0
Max.(no flow) pressure rise, inches water	--	6.85

- Cycles

	8' x 6'	10' x 10'
Aerodynamic cycles per year	76	56
Propulsion cycles per year	8	6
Reactivation cycles per year	27	20
No. of hours of operation of Reactivation cycle	8*	8*

E. ANALYSIS OF EXISTING DRYER OPERATION

To establish the moisture holding capacity of the dryer during both the aerodynamic and propulsion cycles, the following calculations were made for the existing 10' x 10' wind tunnel dryer.

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* 4 hours heating and 4 hours cooling.

Using bone dry alumina as a desiccant (zero equilibrium vapor pressure causes the air leaving the desiccant bed to be at -40°F dew point, [(0.6 gr/lbs]). This performance obviously cannot remain constant over a 2 hour period, since the desiccant's moisture content would rise.

A calculation of the Dryer Moisture removal capability is as follows:

1. Moisture removed from air, $(\frac{\text{lbs}}{\text{hr}})$

   $$= (\text{Mass flow rate}, (\frac{\text{lbs}}{\text{sec}})(3600\ \frac{\text{sec}}{\text{hr}})(\text{specific humidity difference}, \frac{\text{gr}}{\text{lb}})(\frac{1}{7000\ \frac{\text{gr}}{\text{lb}}})$$

2. Alumina moisture content, (%)

   $$= \frac{\text{Weight of water content}}{\text{Weight of Alumina + Weight of Water Content}} \times 100$$

   Note: Weight of water content = Weight of water adsorbed by bone dry Alumina

3. Percent adsorption per pound bone dry Alumina, (%)

   $$= \frac{\text{Weight of water adsorbed by bone dry Alumina}}{1} \times 100$$

Wind tunnel data specifies adsorption per pound bone dry Alumina as

8' x 6'	5.4
10' x 10'	3.33

4. Calculations for 10' x 10' tunnel

   From equations given in 3 above:

   Weight of water adsorbed by bone dry Alumina = 0.0333 tons of water/ton of Alumina

   Therefore, weight of water adsorbed by 1900 tons of Alumina will be

   = 0.0333 x 1900 = 03.27 tons of water

   = 126,540 lbs of water

Substituting this value into equation given in 1 above for two hrs. time period, and solving the equation for average specific humidity gives

$$126{,}540 = (1868)(3600)(78 - x)\ \frac{1}{7000}\ 2$$

$x = 11.06$ gr/lb.

where 78 is the specific humidity of existing air at average summer design conditions.

Therefore maximum acceptable specific humidity will be equal to = 2 x 11.06 = 22.12 gr/lb.

The purpose of the foregoing calculation is as follows:

- To show that to keep -40°F DP temperature for two hours is not possible on the propulsion cycle and as such the tunnels operate at a higher DP (higher moisture level).
- To determine how much water could be absorbed by the bed during a two hour period operative on the propulsion cycle. This use can determine how many hours the bed could be used between reactivations and the possible number of aerodynamic cycles could be run between reactivations based on 50,000 CFM supplied to the tunnel during the aerodynamic cycle.
- To determine the maximum acceptable specific humidity of the air supplied to the tunnel.

5. The moisture removed during aerodynamic cycle using equation given in 1 above:

$$= (50{,}000)\ \frac{1}{13.35}\ \frac{1}{60}\ 3600\ (78.00 - 11.00)\ \frac{1}{7000}$$

= 2149 lbs/hr

Therefore for an aerodynamic cycle (four hours)

2149 x 4 = 8,596 lbs/hr

This gives $\frac{126{,}540}{8{,}596}$ = 14.7 cycles.

If the dryer buildings were vapor sealed, and there was negligible moisture migration, a reactivated bed would be good for at least ten, four hour runs, between reactivations, and still be discharging air at the dew point temperatures lower than you get after two hours of the operation on the propulsion cycle. Unfortunately, the building is not that tight, so reactivation between runs on the aerodynamic cycle must be more frequent than once in every 10 runs. How often, would be a function of the season, since less moisture will infiltrate into the structure during mild weather. To determine the optimum reactivation schedule, bed samples should be analyzed for % water absorbed.

After a propulsion cycle, reactivation may not be necessary, for instance, if the run were made when the outdoor air moisture content is lower than average summer condition. Similar characteristic values can be obtained for 8' x 6' tunnel following same calculation procedures.

F. ENERGY AND COST ANALYSIS

The yearly energy consumed and cost involved to operate the air dryer buildings were calculated for only the aerodynamic cycle since the proposed foregoing modifications are suitable for the aerodynamic cycle and not for propulsion cycle.

1. 10' x 10' Tunnel

a) Gas

- Energy required to heat 721,000 cfm from 40°F to 350°F 240×10^6 Btu/hr.
- No. of hours per reactivation = 4 hrs.
- No. of reactivations per year

  $$\frac{56 \text{ cycle/year}}{4 \text{ cycle/reactivation}} = 14 \text{ reactivation/year}$$
- Energy consumption/year =

  $$(240 \times 10^6) \text{ Btu/hr} \times 4 \frac{\text{hrs.}}{\text{reactivation}}$$

  $$14 \frac{\text{reactivation}}{\text{year}} = 13{,}440 \times 10^6 \text{ Btu/year}$$
- $$\text{Energy cost} = 13{,}440 \frac{\text{Btu}}{\text{year}}\ 2.4 \frac{\$}{1000 \text{ cu.ft.}}\ \frac{1}{1000 \frac{\text{Btu}}{\text{cu.ft.}}}$$

  = $32,256/year

b) Blowers

(Assume that energy consumption is 80% of the blower rated HP)

o Cooling

- Energy cost/year

  $$.746 \text{ KW/BHP} \times (1600 \times .8) \text{ BHP} \times 14 \frac{\text{runs}}{\text{year}} \times 4 \frac{\text{hrs}}{\text{run}} \times .03 \frac{\$}{\text{KWH}}$$

  = $1,604/year

- Heating

  - Energy cost/year

    *Energy cost/year for cooling x $\left(\frac{\text{cfm for heating}}{\text{cfm for cooling}}\right)^3$ =

    \$1,604/year x $\left(\frac{721{,}000}{835{,}000}\right)^3$ = \$1,033 year

  - Total blower energy cost per year (cooling & heating)

    ≈ 1,604 + 1,033 = \$2,637/year

c) <u>Coolers</u>

- Pumps energy cost/year

  $\frac{.746\ \text{KW/BHP}}{3{,}960}$ x $\frac{9{,}330\ \text{GPM}}{.60\ \text{eff.}}$ x 122 ft. WPD x 14 runs/year

  x 4 $\frac{\text{hrs}}{\text{run}}$ x .03 $\frac{\$}{\text{KWH}}$ = \$602/year

d) <u>Cooling Tower</u>

- Fans

  Energy cost/year = (505 x .8) x .746 x 14 x 4 x .03

  = \$506/year

e) <u>Total energy cost/year for existing system</u>

= 32,256 + 2,637 + 602 + 506

= \$36,001/year

f) <u>Total energy cost/cycle for existing system</u>

= 36001 $\frac{\$}{\text{year}}$ / 56 $\frac{\text{cycle}}{\text{year}}$

= \$643/cycle

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* According to the fan laws, the horse power of a fan is proportional to $(\text{CFM})^3$.

2. 8' x 6' Tunnel

a) Gas

- Energy required to heat 420,000 cfm from 40°F to 350°F 140,616,000 Btu/hr.
- No. of hours per reactivation = 4 hrs.
- No. of reactivation per year =

  $$\frac{76\ \text{cycle/year}}{4\ \text{cycle/reactivation}} = 19\ \text{reactivation/year}$$

- Energy consumption/year =

  $$(140{,}616{,}000)\ \text{Btu/hr} \times 4\ \frac{\text{hrs}}{\text{reactivation}} \times 19\ \frac{\text{reactivation}}{\text{year}}$$

  10,686,816,000 Btu/year

- Energy cost = $$10{,}686{,}811{,}000\ \frac{\text{Btu}}{\text{year}}\ \ 2.4\ \frac{\$}{1000\ \text{cu.ft.}}\ \ \frac{1}{1000\ \frac{\text{Btu}}{\text{cu.ft.}}}$$

  = 25,648/year

b) Reactivation Blowers

(Assume that energy consumption is 80% of the blower rated HP)

- Cooling
  - Energy cost/year

    $$.746\ \text{KW/BHP} \times (100 \times .8)\ \text{BHP} \times 19\ \text{runs/year} \times 4\ \frac{\text{hrs}}{\text{run}} \times .03\ \frac{\$}{\text{KWH}}$$

    = $1,360/year
- Heating
  - Energy cost/year

    $$\text{Energy cost/year for cooling} \times \left(\frac{\text{CFM for heating}}{\text{CFM for cooling}}\right)^3$$

    $$= \$1{,}360/\text{year} \times \left(\frac{420{,}000}{600{,}000}\right)^3 = \$466/\text{year}$$

  - Total blower energy cost/year (cooling and heating)

    = 1360 + 466 = $1826/year

c) Coolers

Pumps energy cost/year

$$= \frac{.746\ \text{KW/BHP}}{3960} \times \frac{10{,}000\ \text{GPM}}{.6\ \text{eff.}} \times 122\ (\text{ft. WPD}) \times 19\ \text{runs/year}$$

$$\times\ 4\ \frac{\text{hrs}}{\text{run}} \times .03\ \frac{\$}{\text{KWH}} = \$873/\text{year}$$

d) Cooling Tower

- Fans

  Energy cost/year = (505 x .8) BHP x .746 x 19 x 4 x .03

  = $687/year

e) Total Energy Cost/Year for Existing System

= 24,648 + 1,826 + 873 + 687
= $29,034/year

f) Total Energy Cost/Cycle for Existing System

$$= 29{,}034 \frac{\$}{\text{year}} \quad 76 \frac{\text{cycle}}{\text{year}}$$

= $382/cycle

G. PROPOSED SYSTEMS AND THEIR EVALUATION

In the present mode of operation of aerodynamic cycle the main damper connecting the wind tunnel and the dryer is open. Consequently a large amount of moisture enters the dryer due to the vapor pressure difference between the outdoors and the bone dry activated alumina. This seriously reduces the holding capacity of activated alumina. Therefore the number of aerodynamic cycles that could be achieved between desiccant regenerations is significantly reduced.

In order to reduce the number of reactivation periods of the air dryers in between the aerodynamic cycles, thereby reducing the energy requirements to provide dry air to the wind tunnels, a study was conducted to compartamentalize the activated alumina beds within the dryer building of each wind tunnel. The complexity of such a modification did not appear to be economically feasible. As a consequence of this effort however, the following proposed modifications have been developed to significantly reduce the energy required for the reactivation of large desiccant air dryers in between aerodynamic cycles.

The systems to be considered as proposed modifications consist of:

1. Solar Integrated Dehumidification System
2. Steam Integrated Dehumidification System
3. Heat Recovery in Reactivation Cycles
4. Modifications of Outside Air Dampers in Air Dryer Buildings

The first, second and fourth ones of the proposed modifications will be applicable to aerodynamic cycle only. The third one, however, will be applicable in both aerodynamic and propulsion cycles.

1. Solar Integrated Dehumidification System

a) General Description

The proposed system provides a complete system for dehumidifying 50,000 CFM of outside air being supplied to each of the 8' x 6' and 10' x 10' wind tunnels during the aerodynamic cycle. The addition of this system will be designed and arranged to bypass the existing air dryer when operating on aerodynamic cycle and to be inoperative during propulsion cycle.

b) Functional and Physical Description

The proposed Solar Integrated Dehumidification System addition utilizes a unique combination of a line focusing type solar collector and a solid desiccant type dehumidifier for dehumidifying the supply air as delivered to the 8' x 6' and the 10' x 10' wind tunnels.

In this system the solar collector will generate 300°F or higher temperature hot water to provide energy for regenerating the desiccant utilized in the dehumidification process. A high temperature hot water storage tank will be incorporated into the design to store the solar heated water and minimize the area of the line focusing collectors required for the energy demand. The high temperature hot water will be circulated through the main water distribution circuit by means of a water pump. A supplementary steam boiler and convertor are being incorporated into the proposed system,addition to handle the complete or partial energy requirement for the regeneration of the desiccant of the dehumidification system whenever the solar collectors are unable to supply sufficient energy to sustain the reactivation process.

This system will employ 325 tons packaged refrigeration system consisting of centrifugal compressors, direct expansion cooling coils, and their associated equipment. They will be located adjacent to the existing building air dryer and is connected to the tunnel down stream from the exisitng air dryer by means of ductwork. In order to minimize the initial cost, the existing cooling tower will be utilized by the proposed system with the addition of separate condenser water distribution circuit and water circulating pumps.

The system shall condition 50,000 CFM outside air entering the direct expansion coil at 89°F DB, 103 grs/lb. (in summer design condition) and leaves at 44°F DB, 40 grs./lb. The air leaving the DX coil is then further dehumidifed to an effluent condition of 70°F DB, -40°F DP (0.6 grs./lb) as it is drawn through a solid desiccant dehumidifier. In order to accomplish this, adequate regeneration of the desiccant is required to remove the moisture adsorbed by the desiccant. This is accomplished with outside air which is pre-heated by the HTHW before passing through the desiccant. The heated air rises the desiccant temperature causing the moisture to be released from the desiccant and carried away by the air. The air is then drawn through a regeneration fan and discharged to the weather. The regeneration process is done by means of solar heated water at 270°F.

The solar collector array system logic senses the conditions "Sun" and "System Demand" and places the segments into a "Collection Position". Valves in the header piping control the flow of fluid through the absorber to maintain water temperature as the solar insolation varies. Approximately a 5000 square foot concentrator collector is designed to produce, 4×10^6 Btu/day on a summer average, 1.92×10^6 Btu/day on a winter average. A four day solar energy collection is stored in a 20,000 gallon storage tank. The storage tank capacity is sufficient to provide the energy required for the regeneration process. In the case of insufficient solar collection the supplementary heating system will augment the energy requirements to sustain the regeneration process.

Schematic diagrams psychrometric analysis at different seasons of Solar Intergrated Dehumidification system are given in Figures 3, 4, 5 and 6 respectively.

c. Cost and Energy Analysis

- 10' x 10' Tunnel

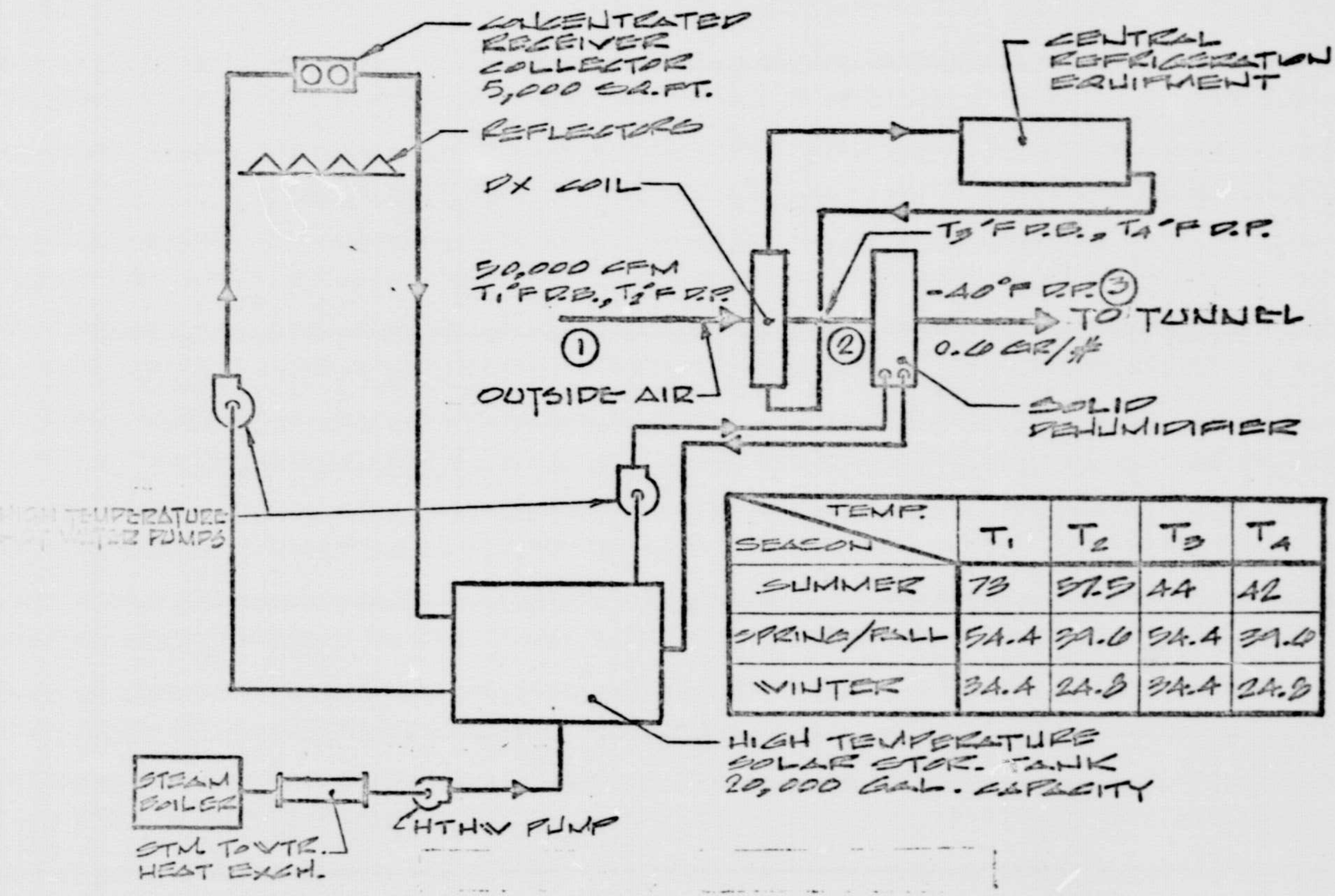
Investment Cost

Solid dehumidifier 50,000 CFM	$81,000
Refrigeration equipment which includes DX Coil, & compressors (325 tons capacity)	87,000
Solar Collector (5000 sq. ft.) @ $25/sq. ft.	75,000
Storage tank & Controls 20,000 gallons	35,000
Other associated equipment	15,000
Boiler & Accessories	20,000
Additional mechanical equipment space	11,000
	324,000
Miscellaneous (10%)	32,400
Total Investment Cost	$356,400

Engery Costs

(1) Refrigeration Compressors

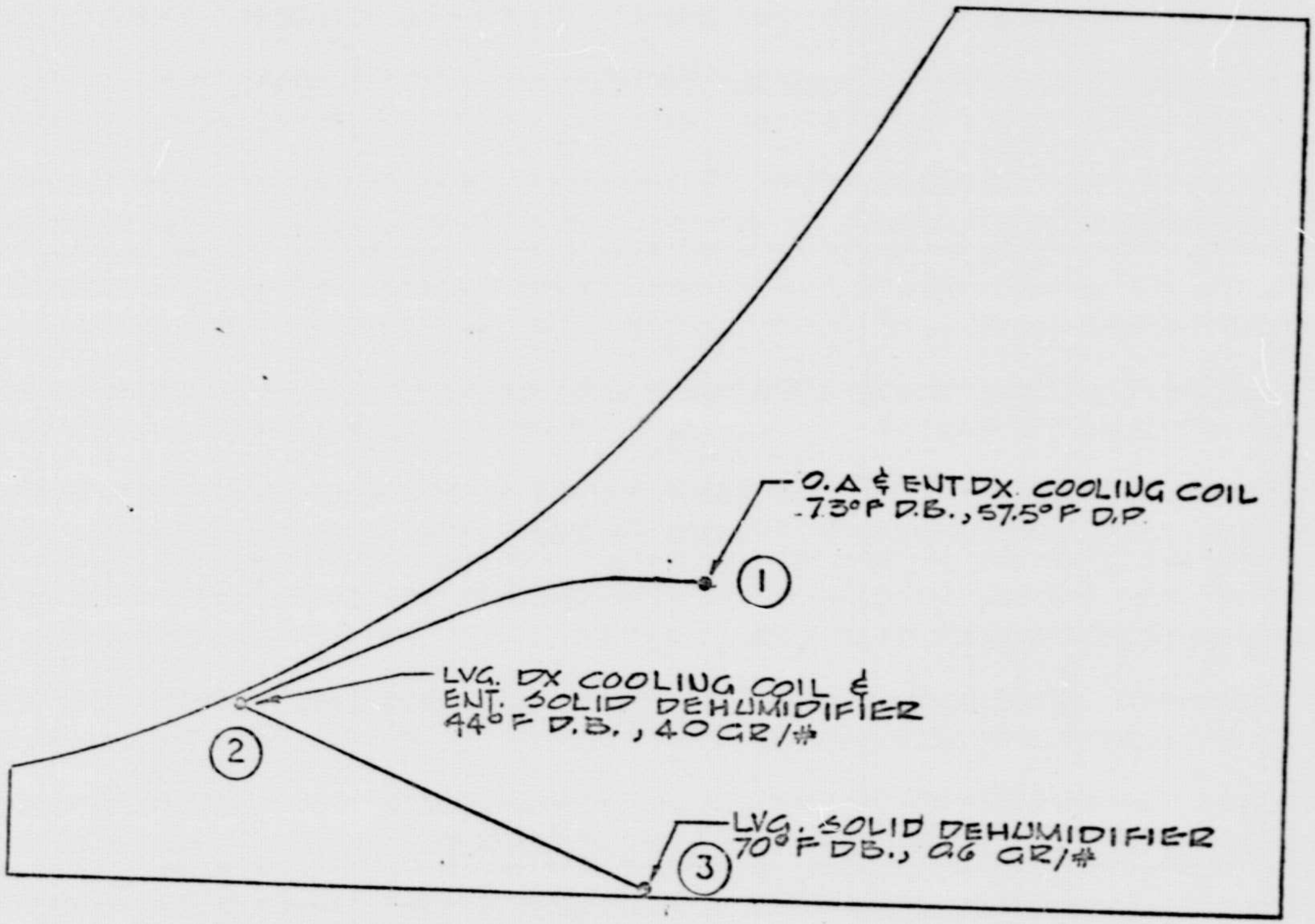
Compressors will operate in summer season only



TEMP. / SEASON	T_1	T_2	T_3	T_4
SUMMER	73	57.5	44	42
SPRING/FALL	54.4	39.6	54.4	39.6
WINTER	34.4	24.8	34.4	24.8

SOLAR INTEGRATED DEHUMIDIFICATION SYSTEM

FIGURE 3



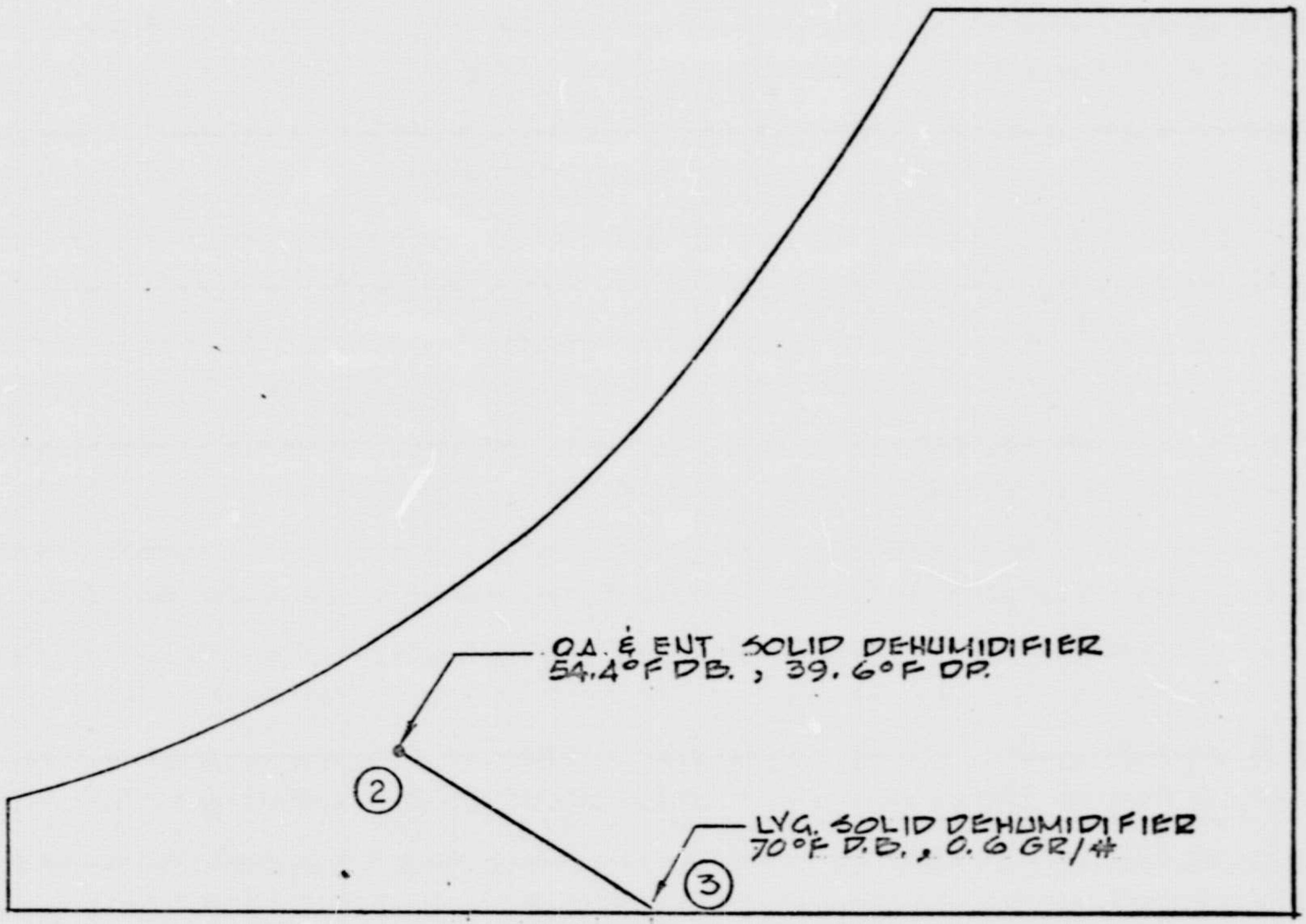
PSYCHROMETRIC ANALYSIS

OF

SOLAR INTEGRATED DEHUMIDIFICATION SYSTEM

SUMMER

FIGURE 4



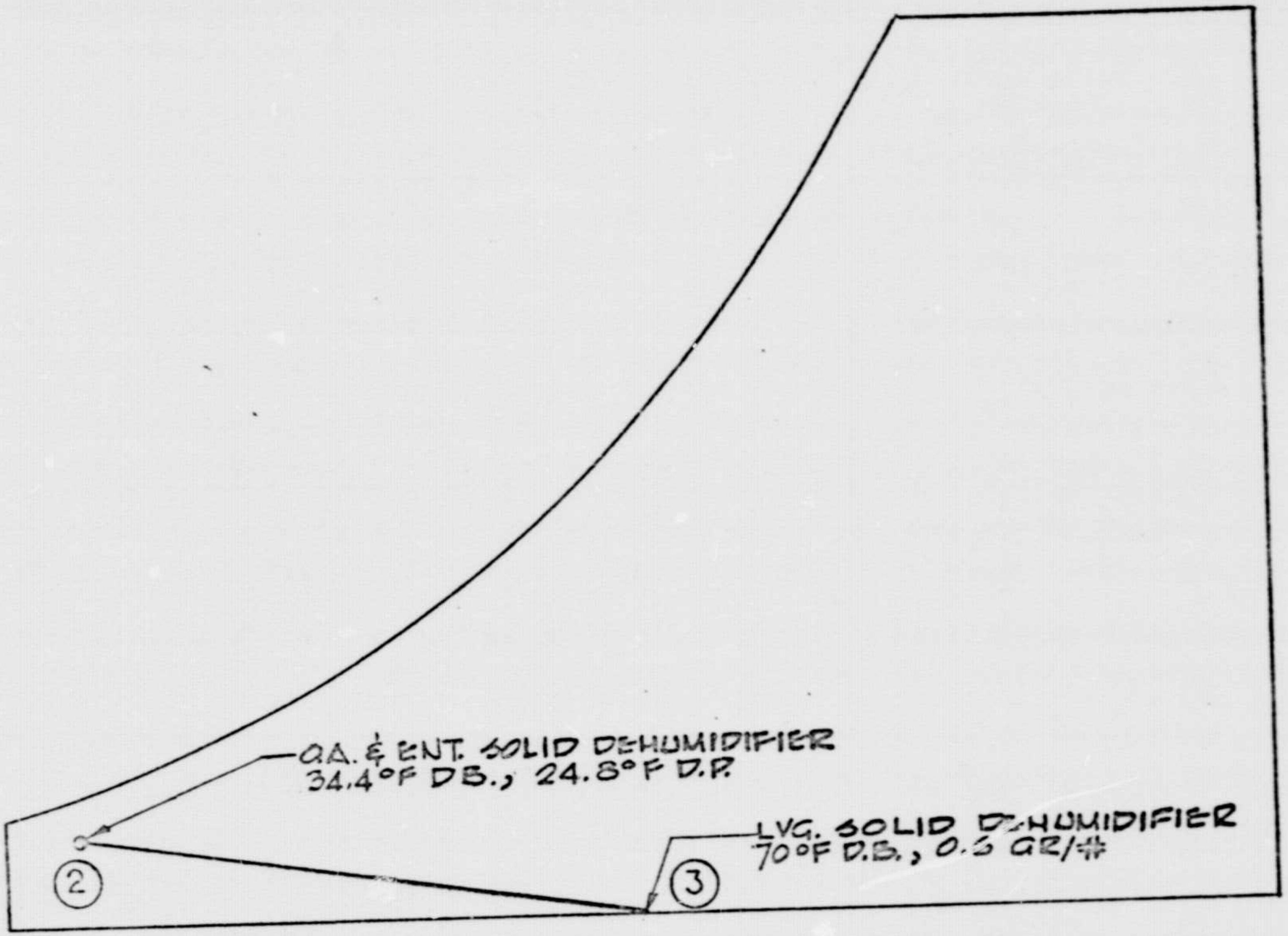
PSYCHROMETRIC ANALYSIS

OF

SOLAR INTEGRATED DEHUMIDIFICATION SYSTEM

SPRING/FALL

FIGURE E



PSYCHROMETRIC ANALYSIS

OF

SOLAR INTEGRATED DEHUMIDIFICATION SYSTEM

WINTER

FIGURE 6

Aerodynamic cycles/summer season =

$$56 \frac{\text{cycles}}{\text{year}} \times \frac{\text{122 days}}{\text{summer season}} \times \frac{1}{365} \times \frac{\text{days}}{\text{year}}$$

= 19 cycles

Average compressors KW in summer season

= 170 KW

Energy cost/year=

$$170 \text{ KW} \times 19 \frac{\text{cycles}}{\text{summer}} \times 4 \frac{\text{hrs}}{\text{cycle}} \times .03 \frac{\$}{\text{KWH}}$$

= \$388/year

(2) Solar pumps

$$\text{Collector capacity} = 5000 \text{ sq.ft.} \times 800 \frac{\text{Btu/day}}{\text{sq. ft.}} \div \frac{\text{8 hr}}{\text{day}}$$

$$= 500{,}000 \text{ Btu/hr}$$

Solar pump GPM (@ 40°F ΔT)

$$= \frac{500{,}000}{500 \times 40} = 25 \text{ GPM}$$

$$\text{Solar pump KW} = \frac{.746 \text{ KW/BHP} \times 25 \text{ GPM}}{3{,}960 \times .65 \text{ eff}}$$

$$\times\ 50 \text{ ft. water pressure drop (WPD)}$$

$$= .36 \text{ KW}$$

Assuming that solar pump runs 8 hrs/day,

4 days/ cycles

$$\text{Energy cost/year} = .36 \text{ KW} \times 56 \frac{\text{cycles}}{\text{year}} \times 4 \frac{\text{days}}{\text{cycle}}$$

$$\times\ 8 \frac{\text{hrs}}{\text{day}} \times .03 \frac{\$}{\text{KWH}} = \$19/\text{year}$$

(3) High Temperature Hot Water (HTHW) Pump

@ 40°F ΔT

$$\text{GPM} = \frac{3 \times 10^6 \text{ Btu/hr}}{500 \times 40} = 150 \text{ GPM}$$

$$\text{KW} = \frac{.746 \times 150 \times 50 \text{ ft WPD}}{3960 \times .65 \text{ eff}}$$

$$= 2.17 \text{ KW}$$

Energy cost/year =

$$2.17 \text{ KW} \times 56 \frac{\text{cycle}}{\text{year}} \times 4 \frac{\text{hrs}}{\text{cycle}}$$

$$\times .03 \frac{\$}{\text{KWH}} = \$14.6/\text{year}$$

(4) Cooling Tower pump

GPM (@10°F ΔT) = 975 GPM

Water Pressure Drop = 50 ft. of water

Energy cost/year =

$$\frac{.746 \times 975 \times 50}{3960 \times .65} \times 19 \frac{\text{cycles}}{\text{summer}} \times 4 \frac{\text{hrs}}{\text{cycle}} \times$$

$$.03 \frac{\$}{\text{KWH}} = \underline{\underline{\$13.6/\text{year}}}$$

(5) Regenerator

Rated HP = 20 HP

Energy cost/year =

$$(20 \times .8) \times .746 \times 56 \times 4 \times .03 = \underline{\underline{\$80/\text{year}}}$$

(6) Heat Added by the Boiler in Winter Time

No. of aerodynamic cycles in winter = 14 cycles

Average collector capacity in winter=

<u>385</u> Btu/sq. ft./day

Total heat collected in 4 days =

385 x [illegible]000 x 4 = 7,700,000 Btu

Heat required per cycle = 12×10^6 Btu

Heat added by boiler per cycle =

$(12 \times 10^6) - (7.7 \times 10^6) = 4.3 \times 10^6$ Btu

$$\text{Cost per cycle} = \frac{4.3 \times 10^6 \times 2.4}{10^6} = \$10.3/\text{cycle}$$

Cost per year = 10.3 x 14 = $144/year

Total energy cost/year

= 388 + 19 + 14.6 + 13.6 + 80 + 144

= $659/year

= $11.77/cycle

- Savings

Savings per year = 36001 - 659 = $35,342/year

Savings per cycle = $ 631/cycle

- Simple Payback Period (without escalation)

Investment cost = $356,400

Savings = 631 $/cycle

	Aerodynamic Cycles/year	Payback period (years)
	56	10.04
	60	9.37
Average	64	8.79
	68	8.27
	72	7.81
	76	7.4

- Simple Payback Period (with escalation)

(1) Based on 56 aerodynamic cycles/year and 10% increase in energy cost per year

Year	Saving/year	Total
77	$35,342	$35,342
78	38,876	74,218
79	42,764	116,982
80	47,040	164,022
81	51,744	215,766
82	56,919	272,685
83	62,611	335,296
84	68,872	404,168

Payback period = 7.3 years

(2) Increasing aerodynamic cycles/year by 4 cycles will decrease the payback period by a factor of 0.94*.

	Aerodynamic cycles/year	Payback period
	56	7.3
	60	6.86
Average	64	6.45
	68	6.06
	72	5.7
	76	5.36

- <u>8' x 6' Tunnel</u>

  - <u>Investment Cost</u>

    Investment cost is the same as in 10' x 10' tunnel

    = \$356,400.

  - <u>Energy Cost</u>

    Energy cost per cycle is the same as in 10' x 10' tunnel

    = \$11.7/cycle

    Energy cost per year = $11.7 \frac{\$}{\text{cycle}} \times 76 \frac{\text{cycles}}{\text{year}}$

    = \$894/year

  - <u>Savings</u>

    Savings per year = 29,034 - 894

    = \$28,140/year

    Saving per cycle $\frac{28,140}{76}$

    = \$370.3/cycle

  - <u>Simple Payback Period (without escalation)</u>

    Investment Cost = \$356,400

    Saving = 370.3 \$/cycle

	Aerodynamic Cycles/Year	Payback Period (Years)
	76	12.58
	80	11.95
Average	84	11.38
	88	10.86
	92	10.39
	96	9.96

---

*Deinvert from simple payback period calculations (without escalation)

- Simple Payback (with escalation)

(1) Based on 76 aerodynamic cycles/year and 10% increase in energy cost per year.

Year	Saving/year	Total
77	$28,140	$28,140
78	30,954	59,094
79	34,049	93,143
80	37,454	130,597
81	41,199	171,791
82	45,320	217,111
83	49,852	266,963
84	54,837	321,800
85	60,321	382,121

Payback period = 8.56 years

(2) Increasing aerodynamics cycles/year by 4 cycles will decrease the payback period by a factor of 0.954.

Aerodynamic Cycles/year		Payback period(years)
	76	8.56
	80	8.17
Average	84	7.79
	88	7.43
	92	7.09
	96	6.76

- Simple Payback (with escalation)

(1) Based on 76 aerodynamic cycles/year and 10% increase in energy cost per year.

Year	Saving/year	Total
77	$28,140	$28,140
78	30,954	59,094
79	34,049	93,143
80	37,454	130,597
81	41,199	171,791
82	45,320	217,111
83	49,852	266,963
84	54,837	321,800
85	60,321	382,121

Payback period = 8.56 years

(2) Increasing aerodynamics cycles/year by 4 cycles will decrease the payback period by a factor of 0.954.

	Aerodynamic Cycles/year	Payback period(years)
	76	8.56
	80	8.17
Average	84	7.79
	88	7.43
	92	7.09
	96	6.76

(5) Steam cost using gas as the primary source for 3 x 10^6 reactivation heat is

$$\frac{3 \times 10^6 \text{ Btu/hr}}{1000 \text{ Btu/MCF}} \times \frac{2.40\$}{\text{MCF}} \times 56 \text{ cycles} \times \frac{4 \text{ hr}}{\text{cycle}} = \$1,612.80$$

(6) Total cost/year = \$2,109.00

= \$37.66/cycle

- Savings

Savings per year = \$36,001 - \$2109 = \$33,832/year

Savings per cycle = \$605/cycle

- Simple payback (without escalation)

Investment cost

= \$279,400.00

Savings per cycle

= 605 \$/cycle

Aerodynamic Cycles/year		Payback Period (Years)
	56	8.24
	60	7.69
Average	64	7.21
	68	6.79
	72	6.41
	76	6.07

e. Simple Payback (With escalation)

(1) Based on 56 aerodynamic cycles/year and 10% increase in energy cost per year.

Year	Savings/Year	Total
77	33892	33892
78	37281	71173
79	41009	112,182
80	45110	157,292
81	49621	206,913
82	54583	261,196
83	60042	321,538

Payback period is 6.3 years

2. Steam Integrated Dehumidification System

a. In this proposed system steam is generated from a boiler located in a new mechanical room adjacent to the existing air dryer building. The dehumidification equipment and the process of generating dehumidified air to -40°F D.P. and 70°F D.B. are similar to the solar integrated dehumidification system with the exception that in this system only steam is used for generating high temperature hot water.

b. Cost and Energy Analysis

The cost and energy analysis is performed for both tunnels during the aerodynamic cycles.

- 10' x 10' Tunnel
  - Investment cost

Solid dehumidifier of 50,000 CFM	$81,000
Refrigeration equipment which includes DX Coil, and compressors (325 tons capacity)	87,000
Boiler and other accessories	20,000
Other associated equipment	15,000
Tank and its accessories	35,000
Additional mechanical equipment	11,000
	$249,000
Miscellaneous	30,400
Total investment cost	$279,400

  - Energy cost

Refrigeration compressors*	$388/year
HTHW pumps*	$14.6/year
Cooling tower pump*	$13.6/year
Regenerator fan*	$80 /year

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*Costs are taken from the energy cost calculations for the solar Integrated Dehumidification System

3. Heat Recovery in Reactivation Cycles

a. During reactivation for both the aerodynamic and propulsion cycles, the hot air used to reactivate the saturated alumina is exhausted into the atmosphere at 303°F*. Energy can be recovered by installing air to air heat exchangers in the intake and exhaust air streams.

b. Energy and cost analysis

The exhaust air and incoming air will be arranged to flow in the opposite directions for achieving maximum efficiency. The potential energy savings, assuming 90% usage on aerodynamic cycle mode, and 4 aerodynamic runs between reactivation, would be as follows:

- 10' x 10' Tunnel

  The heat that can be recovered
  $= (721{,}000\ \text{CFM})(1.08)(303°\text{F} - 40°\text{F}) \times .8$ efficiency
  $= (163{,}834 \times 10^6\ \text{Btu/hr})$.

  - Annual energy saved** = (163,834,000)(4)(20)
    = 13,106.72
  - Operating cost at the rate of $\$2.40/10^6$ Btu

    $$= \frac{13106.72 \times 10^6}{1000 \times 1000} \times 2.4$$

    = $31,456
  - Air to Air Heat Exchanger

    Installed cost = 721,000 CFM x $0.80/CFM
    = $576,800

---

* 303°F is the mean temperature of the air leaving the dryer

** Based on 20 reactivation cycles and 4 hours per reactivation cycle where \$0.80 is the installed cost/CFM.

- Payback = $\frac{576,800}{31,456}$ = 18.4 years

- <u>8' x 6' Tunnel</u>

The heat that can be recovered

= (420,000 CFM) (1.08) (303°F - 40°F) 0.8 = 95.4×10^6

Cycles/year with reactivation cycle being 4 hours

Annual energy recovered = 95.4×10^6 Btu/hr x 4 x 27 cycles

= $10,303.2 \times 10^6$ Btu/yr

- operating cost at the rate of \$2.40/1000 CFM

$$= \frac{10,303.2 \times 10^6}{1000 \times 1000} \times 2.40 = \$24,727.68$$

- Air to air heat exchanger installed cost
  (at the rate of \$.8/CFM)

  = 420,000 x .8 = \$336,000

- Simple payback period = $\frac{\$336,000}{24,727.68}$ = 13.5 years

The above payback analysis indicates that this modification option is not economically viable because of the limited number of required reactivation cycles.

4. <u>Modification of the Outside Air Intake Dampers in the Air Dryer Buildings</u>

When the wind tunnels are operating on the aerodynamic cycle as contrasted to the propulsion cycle, a reduced quantity of air, approximately 50,000 CFM, is all that is required to be induced into the wind tunnel.

During this mode of operation the outdoor intake dampers of the air dryer buildings are fully opened exposing large areas of dry desiccant to the high gran outdoor ambient environment. Because of the large opening of the air intake area, the great difference in vapor pressure of the outdoor air and the activated alumina desiccant, a large amount of moisture migrates from the outdoor air to the activated alumina desciccant. This moisture migration severely reduces the useful adsorption capacity of the activated alumina and limits the possible number of aerodynamic cycles before reactivation of the desiccant beds is required. The unnecssary wasteful moisture migration can be eliminated by reducing the outdoor intake opening. This can be done by keeping the outdoor intake dampers closed and sealed completely during the aerodynamic cycle and providing a 100 sq. ft. opening (just enough for the required 50,000 CFM) in the outdoor intake opening. This modification will significantly increase the possible number of aerodynamic cycles between reactivations.

In order to establish the limitaion imposed and its effect on the energy requirement for reactivation of the desiccant the following calculations were prepared.

- <u>10' x 10' Tunnel</u>

  The amount of moisture transferred from outdoor air is the activated alumina through the large opening of the air intake, lbs of water/hr

  $(\text{intake opening area, ft}^2)\ (2460\ \text{Btu/ft}^2\ \text{hr}/100\ \frac{\text{GR}}{\text{lb.}})$

  $(\text{specific humidity difference}/100, \frac{\text{GR}}{\text{lb}})$

  $(\frac{1}{1060\ \text{Btu/lb of water vapor}}) =$

  $2400 \times 2460^{*} \times (42 - 1.8)/100 \times \frac{1}{1060}$

  $= 2239\ \frac{\text{lb water}}{\text{hr}}$

- <u>8' x 6' Tunnel</u>

  The amount of moisture transferred from outdoor air to the activated alumina through the large opening of the air intake, $\frac{\text{lbs. of water}}{\text{hr}}$

  $= 1600 \times 2460 \times (42 - 1.8)/100 \times \frac{1}{1060}$

  $= 1493\ \frac{\text{lbs of water}}{\text{hr}}$

---

* Data received from Ross Air Systems Division, Midland Ross Corporation

The moisture removed from 50,000 CFM, $\frac{\text{lbs}}{\text{hr}}$ =

$$(\text{Air flow rate, CFM}) \left(\frac{1}{\text{Air Specific Volume, ft}^3/\text{lb}}\right)$$

$$\left(\frac{60\text{ minutes}}{\text{hour}}\right) \left(\text{Specific humidity difference, } \frac{\text{gr}}{\text{lb}}\right)$$

$$\left(\frac{1}{7000\ \frac{\text{gr}}{\text{lb}}}\right) =$$

$$50{,}000 \times \frac{1}{13.35} \times 60 \times (42 - 1.8) \times \frac{1}{7000} = 1290\ \frac{\text{lbs of water}}{\text{hr.}}$$

The above calculations demonstrate that in the present mode of operating the aerodynamic cycle (during which the required moisture removal from the outside air is only 1290 $\frac{\text{lbs of water}}{\text{HR.}}$ the unnecessary wasteful moisture migration associated with, and can not be separated from, the required air dehumidification process because of the large outdoor intake opening, are 2239 and 1493 lbs of water/hr for the 10' x 10' and the 8' x 6' tunnels respectively. Therefore if the unnecessary load is eliminated by reducing the outdoor intake opening, approximately twice as many aerodynamic cycles can be run in the 8' x 6' tunnel and as many as three times in the 10' x 10' tunnel. Thus, based on 56 closed cycle runs on the 10' x 10' tunnel per year and 76 closed cycle runs per year on the 8' x 6' tunnel, the annual savings would be as follows:

Investment Cost

We estimate that the investment cost for doing this modification for each tunnel is = $15,000.

Savings

Unfortunately, the dryer buildings are not vapor sealed and there will be a small amount of moisture migration even after the proposed modification. Thus, we can say that the reactivation cycles can be reduced from 19 to 10 in the 8' x 6' tunnel and from 14 to 7 in the 10' x 10' tunnel.

10' x 10' tunnel

savings/year = ($643/cycle) (7 cycles/year)
= $4501. /year

8' x 6' tunnel

savings/year = ($382/cyle) (9 cycles/year)
= $3438. /year

Simple Payback Period

10' x 10' tunnel

$$\text{Payback period} = \frac{15{,}000}{4501} = 3.33 \text{ years}$$

8' x 6' tunnel

$$\text{Payback period} = \frac{15{,}000}{3438} = 5.4 \text{ years}$$