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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.)

JULY 15, 1976

PREPARED FOR:
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION HEADQUARTERS
FACILITIES ENGINEERING AND MAINTENANCE DIVISION
WASHINGTON, D.C. 20546

BY:
GERSHON MECKLER ASSOCIATES, P.C.
CONSULTING ENGINEERS
WASHINGTON, D.C.
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.
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:

<table>
<thead>
<tr>
<th>Wind Tunnel</th>
<th>Aerodynamic Cycle</th>
<th>Propulsion Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>8' x 6'</td>
<td>76</td>
<td>8</td>
</tr>
<tr>
<td>10' x 10'</td>
<td>56</td>
<td>6</td>
</tr>
</tbody>
</table>

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


C. EVALUATION OF THE PROPOSED MODIFICATIONS

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

<table>
<thead>
<tr>
<th>PROPOSED MODIFICATION NO.</th>
<th>INITIAL INVESTMENT</th>
<th>TOTAL YEARLY SAVING</th>
<th>SIMPLE PAYBACK WITHOUT ESCALATION</th>
<th>SIMPLE PAYBACK WITH ESCALATION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>8' x 6' 10' x 10'</td>
<td>8' x 6' 10' x 10'</td>
<td>8' x 6' 10' x 10'</td>
<td>8' x 6' 10' x 10'</td>
</tr>
<tr>
<td></td>
<td>$</td>
<td>$</td>
<td>Years</td>
<td>Years</td>
</tr>
<tr>
<td>1</td>
<td>356,400</td>
<td>28,334</td>
<td>11.3</td>
<td>7.79</td>
</tr>
<tr>
<td></td>
<td></td>
<td>35,486</td>
<td>8.79</td>
<td>6.45</td>
</tr>
<tr>
<td>2</td>
<td>279,400</td>
<td>25,583</td>
<td>10.92</td>
<td>7.09</td>
</tr>
<tr>
<td></td>
<td></td>
<td>33,457</td>
<td>8.3</td>
<td>5.4</td>
</tr>
<tr>
<td>3</td>
<td>576,000</td>
<td>49,300</td>
<td>17,400</td>
<td>13.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12,202</td>
<td>18.4</td>
<td>--</td>
</tr>
<tr>
<td>4</td>
<td>15,000</td>
<td>3,438</td>
<td>4,501</td>
<td>4.36</td>
</tr>
<tr>
<td></td>
<td>10,000</td>
<td>3,33</td>
<td>3.33</td>
<td>--</td>
</tr>
</tbody>
</table>
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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C. EVALUATION OF THE PROPOSED MODIFICATIONS
D. RECOMMENDATIONS

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C. BASES OF ANALYSIS
D. WIND TUNNEL DATA
E. ANALYSIS OF EXISTING DRYER OPERATION
F. ENERGY AND COST ANALYSIS
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STUDY OF THE APPLICATION OF SOLAR CHEMICAL DEHUMIDIFICATION SYSTEM TO
WIND TUNNEL FACILITIES OF NASA LEWIS RESEARCH CENTER

A. INTRODUCTION

Gershon Meckler Associates, P.C. has prepared this report to assess the feasibility of using a solar dehumidification system for the 8' x 6' and 10' x 10' wind tunnels at the Lewis Research Center (LeRC), Cleveland, Ohio. In this report, the data supplied by NASA LeRC operating personnel, at technical briefings during our visit, have also been incorporated.

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 reactivating 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:

<table>
<thead>
<tr>
<th>Wind Tunnel</th>
<th>Aerodynamic Cycle</th>
<th>Propulsion Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>8' x 6'</td>
<td>76</td>
<td>8</td>
</tr>
<tr>
<td>10' x 10'</td>
<td>56</td>
<td>6</td>
</tr>
</tbody>
</table>

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


D. WIND TUNNEL DATA

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

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

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

- **Heaters**
  - Number of units: 20
  - Btu per unit per hr: 8,000,000
  - Total Btu per hr: 160,000,000
  - Combustion air pressure, oz.: 16
  - Combustion air blower HP: 275
  - Fuel/air ratio - approx.: 12.5:1

- **Coolers**
  - Number of units: 52
  - Total face area sq.ft.: 1,172
  - Maximum water rate, g.p.m.: 10,000
  - Water pressure drop, feet head: 90
  - Air pressure drop, inches water: 1.4
  - Max. Temperature rise, water, °F.: 70
  - Max. Temperature drop, air, °F.: 250

- **Fans**
  - Number of units: 8
  - HP per unit: 125
  - Total HP: 1,000
  - Scfm flow forward (cooling): 600,000
  - Pressure rise forward, inches water: 6.0
  - Max. (no flow) pressure rise, inches water: --
  - Scfm flow reverse (heating): 420,000
  - Pressure rise reverse, inches water: 3.9
  - Max. (no flow) pressure rise, inches water: --

- **Cycles**
  - Aerodynamic cycles per year: 76
  - Propulsion cycles per year: 8
  - Reactivation cycles per year: 27
  - No. of hours of operation of Reactivation cycle: 8

### 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.

* 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, \( \frac{\text{lbs}}{\text{hr}} \)
\[
= \left( \frac{\text{mass flow rate}}{\text{sec}} \right) \left( \frac{1}{3600 \text{ sec/hr}} \right) \left( \frac{\text{specific humidity difference}}{1 \text{ lb}} \right) \\
\left( \frac{7000 \text{ gr}}{1 \text{ lb}} \right)
\]

2. Alumina moisture content, (%)
\[
= \frac{\text{weight of water content}}{\text{weight of Alumina} - \text{weight of water content}} \times 100
\]
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

\[
\begin{array}{c|c}
8' \times 6' & 5.4 \\
10' \times 10' & 3.33
\end{array}
\]

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
\[
= 0.0333 \times 1900 = 03.27 \text{ tons of water}
\]
\[
= 126,540 \text{ lbs of water}
\]

Substituting this value into equation given in 1 above for two hrs. time period, and solving the equation for average specific humidity gives
\[
126,540 = (1868)(3600)(78 - x) \left( \frac{1}{7000} \right) 2
\]
\[
x = 11.06 \text{ gr/lb.}
\]
where 78 is the specific humidity of existing air at average summer design conditions.
Therefore maximum acceptable specific humidity will be equal to
\[ \frac{2 \times 11.06}{1} = 22.12 \, \text{gr/lb}. \]

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:

\[ \frac{1}{13.35} \frac{1}{60} \frac{3600}{7100} (78.00 - 11.00) \frac{1}{7000} = 2149 \, \text{lbs/hr} \]

Therefore for an aerodynamic cycle (four hours)

\[ 2149 \times 4 = 8596 \, \text{lbs/hr} \]

This gives \[ \frac{126540}{8596} = 14.7 \, \text{cycles} \]

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
     \[ 240 \times 10^6 \text{ Btu/hr} \]
   - 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 = \( (240 \times 10^6) \text{ Btu/hr} \times 4 \frac{\text{hrs.}}{\text{reactivation}} \)
     \[ 14 \frac{\text{reactivation}}{\text{year}} = 13,440 \times 10^6 \text{ Btu/year} \]
   - Energy cost = \( 13,440 \frac{\text{Btu}}{\text{year}} \times 2.4 \frac{\$}{1000 \text{ cu.ft.}} \times \frac{1}{1000 \frac{\text{Btu}}{\text{cu.ft.}}} \)
     \[ = \$32,256/\text{year} \]

   b) Blowers

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

   - Cooling
     \[ .746 \text{ KW/BHP} \times (1600 \times .8) \text{ BHP} \times 14 \frac{\text{runs}}{\text{year}} \times 4 \frac{\text{hrs}}{\text{run}} \times .03 \frac{\$}{\text{KWH}} \]
     \[ = \$1,604/\text{year} \]
- Heating
  - Energy cost/year
    *Energy cost/year for cooling x \( \frac{(\text{cfm for heating})^3}{(\text{cfm for cooling})^3} \) =
    
    \[
    $1,604/\text{year} \times \left(\frac{721,000}{835,000}\right)^3 = $1,033/\text{year}
    \]
    - Total blower energy cost per year (cooling & heating)
      = 1,604 + 1,033 = $2,637/year

c) Coolers
- Pumps energy cost/year
  \[
  \frac{.746 \text{ KW/BHP}}{3,960} \times \frac{9,330 \text{ GPM}}{.60 \text{ eff.}} \times 122 \text{ ft. WPD} \times 14 \text{ runs/year}
  \times 4 \frac{\text{hrs}}{\text{run}} \times .03 \frac{\$}{\text{KWH}} = $602/\text{year}
  \]
d) Cooling Tower
- Fans
  Energy cost/year = \((505 \times .8) \times .746 \times 14 \times 4 \times .03\)
  = $506/year

e) Total energy cost/year for existing system
  = 32,256 + 2,637 + 602 + 506
  = $36,001/year

f) Total energy cost/cycle for existing system
  = 36001 \( \frac{\$}{\text{year}} / 56 \frac{\text{cycle}}{\text{year}} \)
  = $643/cycle

* According to the fan laws, the horse power of a fan is proportional to \((\text{CFM})^3\).
2. 81 x 61 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 =
  \[ (140,616,000 \text{ Btu/hr}) \times \frac{4 \text{ hrs}}{\text{ reactivation}} \times 19 \text{ reactivation/year} \]
  10,686,816,000 Btu/year
- Energy cost = \[ 10,686,811,000 \text{ Btu/year} \times 2.4 \text{ \$/1000 cu.ft.} \times \frac{1}{1000 \text{ Btu/cu.ft.}} \]
  = 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/year \times \left( \frac{420,000}{600,000} \right)^3 = $466/year
  - Total blower energy cost/year (cooling and heating)
    = 1360 + 466 = $1826/year

c) Coolers
Pumps energy cost/year
\[ \frac{.746 \text{ KW/BHP}}{3960} \times \frac{10,000 \text{ GPM}}{.6 \text{ eff.}} \times 122 \text{ (ft. WPD)} \times 19 \text{ runs/year} \]
\[ \times 4 \frac{\text{hrs}}{\text{run}} \times .03 \frac{\$}{\text{KWH}} \]
= $3073/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 \( \frac{\$}{\text{year}} \) \( \frac{76 \text{ cycle}}{\text{year}} \)

   = $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 compartmentalize 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 existing 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 dehumidified 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, $4 \times 10^6$ Btu/day on a summer average, $1.92 \times 10^6$ 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 |
| Miscellaneous (10%) | $32,400 |
| Total Investment Cost | $356,400 |

Energy Costs

(1) Refrigeration Compressors

Compressors will operate in summer season only
Psychrometric Analysis of Solar Integrated Dehumidification System

Winter

Figure 0
Aerodynamic cycles/summer season =
\[
\frac{56 \text{ cycles}}{\text{year}} \times \frac{122 \text{ days}}{\text{summer season}} \times \frac{1}{365} \times \frac{\text{days}}{\text{year}} = 19 \text{ cycles}
\]

Average compressors KW in summer season
= 170 KW

Energy cost/year =
\[
170 \text{ KW} \times 19 \text{cycles} \times 4 \frac{\text{hrs}}{\text{cycle}} \times 0.03 \frac{\$}{\text{KWH}}
\]
= $388/year

(2) Solar pumps

Collector capacity = 5000 sq.ft. \times 800 \frac{\text{Btu/day}}{\text{sq. ft.}} \div 8 \text{ hr/day}
= 500,000 \text{ Btu/hr}

Solar pump GPM (@ 40°F ΔT)
\[
\frac{500,000}{500 \times 40} = 25 \text{ GPM}
\]

Solar pump KW
\[
\frac{.746 \text{ KW/BHP} \times 25 \text{ GPM}}{3960 \times .65 \text{ eff}}
\]
\[
x 50 \text{ ft. water pressure drop (WPD)} \times .36 \text{ KW}
\]

Assuming that solar pump runs 8 hrs/day,
4 days/ cycles

Energy cost/year = .36 KW \times 56 \frac{\text{cycles}}{\text{year}} \times 4 \frac{\text{days}}{\text{cycle}}
\times 8 \frac{\text{hrs}}{\text{day}} \times 0.03 \frac{\$}{\text{KWH}} = $19/year

(3) High Temperature Hot Water (HTHW) Pump

@ 40°F ΔT

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

KW = \[
\frac{.746 \times 150 \times 50 \text{ ft WPD}}{3960 \times .65 \text{ eff}}
\]
= 2.17 KW
Energy cost/year =

\[ 2.17 \text{ KW} \times 56 \frac{\text{cycle}}{\text{year}} \times 4 \frac{\text{hrs}}{\text{cycle}} \times 0.03 \frac{\text{KWH}}{\text{cycle}} = \$14.6/\text{year} \]

(4) Cooling Tower pump

GPM (\@10^\circ F \Delta T) = 975 GPM

Water Pressure Drop = 50 ft. of water

Energy cost/year =

\[ \frac{0.746 \times 975 \times 50}{3960 \times 0.65} \times 19 \frac{\text{cycles}}{\text{summer}} \times 4 \frac{\text{hrs}}{\text{cycle}} \times 0.03 \frac{\text{KWH}}{\text{cycle}} = \$13.6/\text{year} \]

(5) Regenerator

Rated HP = 20 HP

Energy cost/year =

\[ (20 \times 0.8) \times 0.746 \times 56 \times 4 \times 0.03 = \$80/\text{year} \]

(6) Heat Added by the Boiler in Winter Time

No. of aerodynamic cycles in winter = 14 cycles

Average collector capacity in winter = 385 Btu/sq. ft./day

Total heat collected in 4 days =

\[ 385 \times 0.000 \times 4 = 7,700,000 \text{ Btu} \]

Heat required per cycle = \( 12 \times 10^6 \) Btu

Heat added by boiler per cycle =

\[ (12 \times 10^6) - (7.7 \times 10^6) = 4.3 \times 10^6 \text{ Btu} \]

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

Cost per year = \$10.3 \times 14 = \$144/\text{year} \]

Total energy cost/year

\[ = 388 + 19 + 14.6 + 13.6 + 80 + 144 = \$659/\text{year} \]

\[ = \$11.77/\text{cycle} \]
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

<table>
<thead>
<tr>
<th>Aerodynamic Cycles/year</th>
<th>Payback period (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>56</td>
<td>10.04</td>
</tr>
<tr>
<td>60</td>
<td>9.37</td>
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<td>68</td>
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</tr>
<tr>
<td>72</td>
<td>7.81</td>
</tr>
<tr>
<td>76</td>
<td>7.4</td>
</tr>
</tbody>
</table>

Simple Payback Period (with escalation)

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

<table>
<thead>
<tr>
<th>Year</th>
<th>Saving/year</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>77</td>
<td>$35,342</td>
<td>$35,342</td>
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<tr>
<td>78</td>
<td>38,876</td>
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<tr>
<td>79</td>
<td>42,764</td>
<td>116,982</td>
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<tr>
<td>80</td>
<td>47,040</td>
<td>164,022</td>
</tr>
<tr>
<td>81</td>
<td>51,744</td>
<td>215,766</td>
</tr>
<tr>
<td>82</td>
<td>56,919</td>
<td>272,685</td>
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<tr>
<td>83</td>
<td>62,611</td>
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<tr>
<td>84</td>
<td>68,872</td>
<td>404,168</td>
</tr>
</tbody>
</table>

Payback period = 7.0 years
(2) Increasing aerodynamic cycles/year by 4 cycles will decrease the payback period by a factor of 0.94*. 

<table>
<thead>
<tr>
<th>Aerodynamic cycles/year</th>
<th>Payback period</th>
</tr>
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<tbody>
<tr>
<td>56</td>
<td>7.3</td>
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<tr>
<td>60</td>
<td>6.86</td>
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<tr>
<td>Average 64</td>
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<tr>
<td>68</td>
<td>6.06</td>
</tr>
<tr>
<td>72</td>
<td>5.7</td>
</tr>
<tr>
<td>76</td>
<td>5.36</td>
</tr>
</tbody>
</table>

8' x 6' Tunnel

- Investment Cost
  Investment cost is the same as in 10' x 10' tunnel = $356,400.

- Energy Cost
  Energy cost per cycle is the same as in 10' x 10' tunnel = $11.7/cycle
  Energy cost per year = 11.7 \( \frac{\$}{cycle} \) \times 76 \( \frac{cycles}{year} \)
  = $894/year

- Savings
  Savings per year = 29,034 - 894
  = $28,140/year
  Saving per cycle \( \frac{28,140}{76} \)
  = $370.3/cycle

- Simple Payback Period (without escalation)
  Investment Cost = $356,400
  Saving = 370.3 $/cycle

<table>
<thead>
<tr>
<th>Aerodynamic Cycles/Year</th>
<th>Payback Period (Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>76</td>
<td>12.58</td>
</tr>
<tr>
<td>80</td>
<td>11.95</td>
</tr>
<tr>
<td>Average 84</td>
<td>11.38</td>
</tr>
<tr>
<td>88</td>
<td>10.86</td>
</tr>
<tr>
<td>92</td>
<td>10.39</td>
</tr>
<tr>
<td>96</td>
<td>9.96</td>
</tr>
</tbody>
</table>

*Deinvert in 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.

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

Payback period = 8.56 years

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

<table>
<thead>
<tr>
<th>Aerodynamic Cycles/year</th>
<th>Payback period(years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>76</td>
<td>8.56</td>
</tr>
<tr>
<td>80</td>
<td>8.17</td>
</tr>
<tr>
<td>Average</td>
<td>7.79</td>
</tr>
<tr>
<td>88</td>
<td>7.43</td>
</tr>
<tr>
<td>92</td>
<td>7.09</td>
</tr>
<tr>
<td>96</td>
<td>6.76</td>
</tr>
</tbody>
</table>
**Simple Payback (with escalation)**

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

<table>
<thead>
<tr>
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<td>77</td>
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</table>

Payback period = 8.56 years

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

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>76</td>
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<tr>
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<tr>
<td>Average 84</td>
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<tr>
<td>88</td>
<td>7.43</td>
</tr>
<tr>
<td>92</td>
<td>7.09</td>
</tr>
<tr>
<td>96</td>
<td>6.76</td>
</tr>
</tbody>
</table>
(5) Steam cost using gas as the primary source for 3 x 10^6 reactivation heat is

\[
\frac{3 \times 10^6 \text{ Btu/hr}}{1000 \text{ Btu/MCF}} \times \frac{2.405 \text{ MCF}}{\text{cycle}} \times 56 \text{ cycles} \times \frac{4 \text{ hr}}{\text{cycle}} = 1,612.80\text{ Btu/MU} \times \text{MCF/cycle}
\]

(6) Total cost/year

\[
= 2,109.00
\]

\[
= 37.66/\text{cycle}
\]

Savings

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

Savings per cycle = $605/\text{cycle}

**Simple payback (without escalation)**

- Investment cost = $279,400.00
- Savings per cycle = $605/\text{cycle}

<table>
<thead>
<tr>
<th>Aerodynamic Cycles/year</th>
<th>Payback Period (Years)</th>
</tr>
</thead>
<tbody>
<tr>
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<tr>
<td>60</td>
<td>7.69</td>
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<tr>
<td>Average</td>
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<tr>
<td>68</td>
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</tr>
<tr>
<td>72</td>
<td>6.41</td>
</tr>
<tr>
<td>76</td>
<td>6.07</td>
</tr>
</tbody>
</table>

e. **Simple Payback (With escalation)**

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

<table>
<thead>
<tr>
<th>Year</th>
<th>Savings/Year</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
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<td>33892</td>
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<tr>
<td>79</td>
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<td>45110</td>
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<td>81</td>
<td>49621</td>
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<td>54583</td>
<td>261,196</td>
</tr>
<tr>
<td>83</td>
<td>60042</td>
<td>321,538</td>
</tr>
</tbody>
</table>

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
    - Miscellaneous $30,400
    - **Total investment cost** $279,400
  - **Energy cost**
    - Refrigeration compressors* $388/year
    - HTHM pumps* $14.6/year
    - Cooling tower pump* $13.6/year
    - Regenerator fan* $80 /year

*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
  
  \[
  = (721,000 \text{ CFM})(1.08)(303°F - 40°F) \times 0.8 \text{ efficiency}
  = (163,834 \times 10^6 \text{ Btu/hr}).
  \]

  - Annual energy saved** = \((163,834,000)(4)(20)\)
    = 13,106.72
  - Operating cost at the rate of \$2.40/10^6 \text{ Btu}
    \[
    = \frac{13,106.72 \times 10^6}{1000 \times 1000} \times 2.4
    = \$31,456
    \]

  - **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.

\[
\text{Payback} = \frac{576,800}{31,456} = 18.4 \text{ years}
\]

8' x 6' Tunnel

The heat that can be recovered

\[
= (420,000 \text{ CFM}) (1.08) (303°F - 40°F) 0.8 = 95.4 \times 10^6
\]

Cycles/year with reactivation cycle being 4 hours

Annual energy recovered = 95.4 \times 10^6 \text{ Btu/hr} \times 4 \times 27 \text{ cycles}

\[
= 10,303.2 \times 10^6 \text{ Btu/yr}
\]

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

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

- Air to air heat exchanger installed cost

(at the rate of $0.8/\text{CFM})

\[
= 420,000 \times 0.8 = $336,000
\]

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

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

4. Modification of the Outside Air Intake Dampers in the Air Dryer Buildings

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 desiccant. 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 unnecessary 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 limitation imposed and its effect on the energy requirement for reactivation of the desiccant the following calculations were prepared.

- **10' x 10' Tunnel**

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

  \[
  \frac{\text{lbs of water/hr}}{\text{(intake opening area, ft}^2\text{)}} \times (2460 \text{ Btu/ft}^2 \text{ hr/100 GR}) \times \frac{1}{1060} \times (42 - 1.8) / 100 \times \frac{1}{1060} = 2239 \ \text{lb water/hr}
  \]

- **8' x 6' Tunnel**

  The amount of moisture transferred from outdoor air to the activated alumina through the large opening of the air intake,

  \[
  \frac{\text{lbs of water/hr}}{\text{(intake opening area, ft}^2\text{)}} \times (2460 \text{ Btu/ft}^2 \text{ hr/100 GR}) \times \frac{1}{1060} \times (42 - 1.8) / 100 \times \frac{1}{1060} = 1493 \ \text{lb water/hr}
  \]
The moisture removed from 50,000 CFM, $\frac{\text{lbs}}{\text{hr}} = \frac{1}{\text{Air Specific Volume, } \text{ft}^3/\text{lb}} \times \frac{\text{Air flow rate, CFM}}{(\text{60 minutes/ hour})} \times (\text{Specific humidity difference, } \frac{\text{gr}}{\text{lb}}) = \frac{1}{7000 \frac{\text{gr}}{\text{lb}}} = 50,000 \times \frac{1}{13.35} \times 60 \times (42 - 1.8) \times \frac{1}{7000} = 1290 \text{ lbs of water/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 lbs of water/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/cycle) (9 cycles/year)
= $3438. /year

Simple Payback Period

10' x 10' tunnel
Payback period = $15,000 $4501 = 3.33 years

8' x 6' tunnel
Payback period = $15,000 $3438 = 5.4 years