SPECIFICATIONS

for the

TEMPERATURE AND HUMIDIFICATION CONTROL UNITS

of the

MICROMETEOROLOGICAL WIND TUNNEL

at

COLORADO STATE UNIVERSITY

Contract Number DA-36-039-SC-80371

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1. General Description

1.1 Introduction

Colorado State University is designing and constructing a wind tunnel for application in meteorological research. This wind tunnel, whose plan view is shown in the appended Plan 1, has square cross sections everywhere except at the air drive section and adjacent duct parts where it is round or transitioning from round to square. It is powered by an aircraft propeller driven by a 200 kw. D.C. motor, which permits speed variation of the air in the test section from approximately 5 fps to 100 fps. Also controlled will be the humidity and the temperature of the wind tunnel air flow, as well as the surface temperature of a section of the test section floor. The performance specifications are attached.

On the basis of the performance requirements, a system has been designed at Colorado State University which is described by these specifications. This system will not only meet the requirements of the performance specifications but in some respects purposely exceeds them.

1.2 Scope of specifications

These specifications cover those parts of the wind tunnel control system which pertain to the establishment and control of the ambient temperature (= temperature of the air flow as measured at a specified point near the entrance to the test section), of the ambient humidity, and of the (cooled) temperature of a part of the test section floor.

1.3 Description of wind tunnel

General considerations on the availability of space and optimum performance of the tunnel yield a layout for the cooling and heating system as indicated in Plan 1. At the entrance of the test section, at point B, the humidity sensor (see 3.2, Item 14b)* and the temperature sensor (see 2.5, Item 5a) are located. They are connected to thermostats and humiditystats which are fastened to the outside of the test section wall at Station B. These switches control the humidity and temperature of the ambient air. Temperature sensors and humidity sensors are connected to recorders on the control panel (see 2.5, Item 5d).

The part of the test section floor with adjustable temperatures (cold plate, see 4) begins approximately 40 feet downstream from the test section entrance. In it, 9 feet from the leading edge in the center of the plate, a second temperature sensor (see 2.5, Item 5a) is located. This sensor is connected to a thermostat which controls the overall plate temperature in those cases where it is lower than the temperature of the ambient air.

The cold plate is 40 feet long and approximately 6 feet wide. All along the west side of the test section extends the control panel for the plate (see Fig. 5). It contains not only the valve wheels for controlling the flow of coolant in the ducts under the plate, but also the electrical controls for the hot plate heaters as well as the indicators for the monitoring thermocouples. The heaters, electrical controls, and temperature indicators for the hot plate are not part of these specifications.

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* The paragraph numbers refer to the paragraphs in which the specifications for the mentioned item are outlined.

The southeast and southwest corners of the wind tunnel are designed to allow for opening the tunnel to the outside air, thus making possible either a recirculating or an open circuit type tunnel.

Downstream of the drive section the return duct is gradually expanding to an 18' x 18' cross section, which is reached at section A. Here the coils for cooling, heating, or dehumidifying the ambient air (see 2. 5, Item 6) are located. A drain is available in the neighborhood of the coils to allow draining during defrosting, or dehumidification.

At a distance of 16 feet downstream from the coils, the humidification nozzles (see 3. 2, Item 11) are built into the wall. They can be connected to a water outlet which is available on a column near the north wall of the building as shown in Plan 1.

After leaving the humidification section, the air is turned by two sets of turning vanes into the entrance cone of the test section. It passes four screens which reduce the turbulence level in the air stream and straightens it before entering the test section.

2. The Cooling, Heating, and Dehumidification Systems

2. 1 Design cases

On the basis of the contract specifications, all possible cases of wind tunnel operation have been considered and the requirements for cooling, heating, and dehumidification have been evaluated. Eight cases, which are representative of the requirements on the system, are listed in Table 1. They contain all the features which must be satisfied with the refrigeration system. The main features are:

a. The coil area should be variable.

b. The coils should be designed to allow independent heating and cooling of parts of the coil areas.

c. Plate cooling and coil cooling must be possible simultaneously.

d. Plate heating and coil cooling must be possible simultaneously.

e. Plate cooling and coil heating and cooling must be possible simultaneously.

2.2 Coil design

In order to provide all the features mentioned above, it must be possible to supply one-half of the coil area independently of the other half. Since at the same time a uniform distribution of temperatures in the air stream is desirable, a design as the one shown in Fig. 1 suggests itself. The two independent coil systems, hereafter referred to as coil bank 1 and coil bank 2, are staggered in the manner shown in Fig. 1. They consist each of 6 coil units of 3 feet height and 9 feet length. The design requires four manifolds on each side of the total coil area. Specifications for coils and manifolds are given in paragraph 2.5. The application of the wind tunnel requires that the coils be removed occasionally. Therefore, there should be valves and couplings everywhere between coils and manifolds, so that each coil section can be removed separately. The valves shall also be used to adjust the flow in the coil sections in such a manner that each section cools or heats equally. For coil valves and manifolds a lateral area is provided as shown in detail A of Plan 1. This area can be increased if necessary.

The sides of the coil sections will be bolted to vertical angle irons as shown in detail A of Plan 1. If necessary, a center beam will be provided between east and west coil areas, as indicated in Fig. 1.

TABLE 1: CAPACITIES AND OPERATIONS OF COOLING AND HEATING SYSTEMS

Case	Power input of drive (KW)	Air			Plate Temp. ^{0}F	Coil area needed (in area units)	Heating (H) or cooling (C) requirements (BTU/hr)			Operation		Remarks
		Ve- cit* fp	Temper- ature ^{0}F	% relative humidity			Plate	Bank 1	Bank 2	System 1 Operates on	System 2 Operates on	
1	20		200	15	40	1	50,000 C	250,000 H	50,000C	Bank 1	Plate + Bank 2	Max heating
2	20		200	--	Ambient	1	--	200,000 H	40,000C	Bank 1	Bank 2	
3	75		32	15	Ambient	3	--	230,000 C	230,000C	Bank 1	Bank 2	
4	75		32	95	Ambient	1	--	460,000C	(460,000C)	Bank 1 (or 2)	--	
5	75		32	15	200	2	el. heating	460,000C	(460,000C)	Bank 1 (or 2)	--	System 1 operates alternately on bank 1 or 2
6	75		32	95	200	1	el. heating	460,000C	(460,000C)	Bank 1 (or 2)	--	
7	200		50	--	Ambient	4	--	460,000C	460,000C	Bank 1	Bank 2	
8	200		200	--	32	4	250,000C	230,000C	230,000C	Bank 1 and 2	Plate	

*Velocity rers to minimum unobstructed air flow at section where coil banks will be located

2. 3 Heating and cooling systems

For satisfying all design requirements, the coil banks and the plate must be cooled by two independent systems. They are schematically shown in Fig. 2. Each system must be capable of removing 460, 000 B. T. U. per hour from the coil banks. This requires a maximum capacity of the refrigeration unit of 920, 000 B. T. U. per hour.

System 1 is the system which generally will be used first. It is shown as solid line in Fig. 2. It supplies the coils only, but can be changed from hot to cold. For this purpose, valves 1 and 2 are provided. If possible, provisions should be made to prevent simultaneous opening of both valves at the same time. Downstream of valves 1 and 2 is the pump station. The large pump (see 2. 5, Item 3) of the station is set in operation by the main power switch. The small pump of the station is switched on or off by a thermostatically controlled switch (see 2. 5, Item 4) which responds to temperature changes of the ambient air.

Valves 5 and 6 of system 1 control the distribution of refrigerant flow to the coils. By opening valve 6 but keeping valves 5 closed, only coil bank 1 is operated on; by opening valves 5 but keeping valves 6 closed only coil bank 2 is operated on. Opening of both valve sets allows operation of system 1 on both banks as is desired in those cases where large areas with low cooling input are required (for example case 8 of Table 1).

System 2 is shown as dashed line in Fig. 2. It is used if heavy refrigeration loads are required, or if part of the coils are hot and part of them are cold, or if a cold plate is needed. The operation of the pumps corresponds to these applications. The large pump is used, as in the case of system 1, for coarse setting of the desired temperature, and is therefore only manually controlled. The small pump, however, not only has thermostatically on-off control depending on the temperature of the ambient air, but it also can be switched to respond to a thermostatically controlled switch (see 2.5, Item 5a) which switches on and off according to the temperature of the plate. Figure 3 schematically shows the circuit for the pump switches of both systems. (Since the possibility of interchanging system 1 and system 2 must be available, the same switching circuit is used for both systems.)

Valves 3 or 4, both manually controlled, are operated if system 2 supplies either the plate, or the coils, or both. Valves 7 are used only for interchanging systems 1 and 2 in case of repairs or other emergencies. The control procedures have been summarized in Table 2 for convenient reference.

2.4 Operating of heating and cooling systems

The coils are used for heating, cooling, or dehumidifying the ambient air. Accordingly, operation schedules have been worked out which are shown in Table 1 for each design case.

In case 1, system 1 operates on coil bank 1, heating the air. Since a humidity control can only be provided by adding water through the spray nozzles, and extracting water by condensation on cold coils, in this case system 2 shall not only cool the plate but also cool one coil bank. No control of the temperature of the cold coils is then possible except a manual control (of valves 4 and 3). The temperature of the cold coils therefore must be set lower than required for equilibrium, and water must be added continuously by spraying. Constant conditions will be maintained automatically since spraying must be servo-controlled (see 3.2, Item 13). Case 1 and similar other cases require heating of the air, which will be accomplished by closing valve 1 and opening valve 2 and supplying hot fluid.

Case 2 is similar to case 1, except that the plate is not in operation. It requires, therefore, only that valve 3 be closed.

TABLE 2: SUMMARY OF CONTROL PROCEDURES

Control Type	Control Procedure
Ambient temperature	
a. raising and lowering temperature of refrigeration unit:	thermostat,to be set manually according to empirical rules, controlling coolant temperature.
b. switch pumps on and off (also speed reduction of large pumps):	thermostat, to be set manually,with sensor in test section entrance, controls pump motor current.
c. valves in coolant supply lines:	manually controlled, to be set such that best operation of pumps result.
Ambient humidity	
a. raising and lowering humidity:	humiditystat, to be set manually, with sensor in test section entrance, controls on-off valve supplying spray nozzles. In the case where ambient air is hot and humidity too high, at least one bank must bé on refrigeration, at manually controlled cold temperatures.
Plate temperature	
a. controlling overall low temperatures:	for this condition, the coolant temperature is set on refrigeration unit for ambient air temperature; therefore thermostat with sensor in plate controls pump (on-off), with best pump operation controlled by valves in supply line which are manually operated.
b. controlling local low temperatures:	thermocouples in plate connected to recorders indicate local temperatures; manual operation of valves in each duct brings temperature to desired value as indicated on recorder.

It would permit also setting the temperature of the cold coils on an automatic control responding to the humidity sensor, a feature which may be added later if more satisfactory performance appears desirable.

In case 3 both systems operate on both banks at half capacity, thus making a large cooling surface available to cool the air flow.

In case 4 defrosting may be desirable after some hours of operation. This will be accomplished by changing coil banks at time intervals which have to be determined experimentally. If found necessary, electrical heaters will be added at a later date or, if feasible, hot liquid will be sent through the coils. Calculations show, however, that no serious danger of frosting exists.

Cases 5 and 6 are similar to cases 3 and 4 respectively, except that the cooling capacity must be slightly increased.

Case 7 is the case of maximum cooling, which requires operation of both systems on both banks at full capacity. No specifications are given on the obtainable maximum humidity.

In case 8, system 1 operates at about full capacity on banks 1 and 2, while system 2 operates on the plate. Again, no specifications can be given for maximum equilibrium humidity.

2.5 Specifications for cooling, heating, and dehumidification systems

The contractor shall supply and install (unless otherwise specified), under due consideration of applicable standards and accepted practices, with help of skilled personnel and by using best practical materials, the following items pertaining to the cooling, heating and dehumidification systems. The design principles and design values outlined in the preceeding sections are to be adhered to.

ITEM 1: Refrigeration unit

a. The unit shall be capable of supplying continuously 920,000 B.T.U. per hour refrigeration into 2 independent refrigeration systems. Each of the two independent systems will be capable of supplying 460,000 B.T.U. per hour of refrigeration simultaneously.

b. The unit shall operate on 440 V, 3 phase, 60 cycle, electric power.

c. The unit shall be supplied with the necessary controls to permit changing coolant temperature from the lowest design temperature up to 20°F above lowest design temperature.

d. The unit shall employ a refrigerant which can be heated and used as the heating fluid also. This fluid shall neither under hot nor under cold conditions be corrosive to valves, pipe lines, coils, etc. The refrigerant will be nontoxic and nonexplosive.

ITEM 2: Heating unit

a. The heating unit shall be capable to supply continuously 250,000 B.T.U. per hour heating through system 1 into either part of the coil system (described as coil banks).

b. The unit shall operate on electric power, 440 V, 3 phase, 60 cycle. No specifications are given for any electrical power necessary for control circuits, lights, etc.

c. The unit shall be supplied with the necessary controls to permit changing the temperature of the fluid leaving the unit from a maximum design temperature (to be chosen by the contractor) to a value 20° F below maximum design temperature.

ITEM 3: Two large pumps for pump stations (Main pumps)

a. Each of the main pumps must have a maximum capacity of 4/5 maximum discharge for each system, either of hot or of cold liquid, at such pressures as are necessary to overcome all resistances of pipe systems, conduits, coils, etc., existing in the system either for coils or plate supply, at conditions when all pumps are running at maximum capacity.

b. Each pump must be made of materials which will not corrode under the influence of the coolant used for the system. All moving parts must be easily exchangeable and readily accessible for lubrication (if needed).

c. Each pump must be driven by a drip proof wound rotor induction motor of sufficient HP rating which permits to adjust the motor speed to half maximum design speed.

d. Each motor must operate on 440 V, 3 phase, 60 cycle electric power, and must be sufficiently equipped with breaker, starter, etc.

e. Each motor must be equipped with a switch as shown schematically in Fig. 3.

f. Each motor and pump must be mounted coaxial.

g. Each pump must be equipped with a throttling valve (valves 8 of Fig. 2) which permits control of the pressures.

h. Each pump must be equipped with a check valve (valves 9 in Fig. 2) which prevents back flow through pump.

ITEM 4: Two small pumps for pump station

a. Each of the pumps must have a maximum capacity of 1/5 maximum discharge for each system, either of hot or cold liquid, at such pressures as are necessary to overcome all resistances of pipe systems, conduits, coils, etc. existing in the system either for coils or plate supply, at conditions when all pumps are running at maximum discharge.

b. Each pump must be made of materials which will not corrode under the influence of the coolant used for the system. All moving parts must be easily exchangeable and readily accessible for lubrication (if needed).

c. Each pump must be driven by a drip proof, explosion proof, induction motor of sufficient HP rating.

d. Each motor must operate on 440 V, 3 phase, 60 cycle electric power and must be of sufficient capacity to be supplied with breaker, starter, etc.

e. Each motor must be equipped with a switch as shown schematically in Fig. 3. The switching unit shall consist of 4 parts: (1) the main power switch, (2) a four position switch, (3) a thermostatically controlled switch responding to plate temperature and (4) a thermostatically controlled switch responding to ambient air temperature. The switches shall be of sufficient capacity to either handle the pump power, or to operate switching relays.

f. Each motor and pump must be mounted coaxial.

g. Each pump must be equipped with a throttling valve (valves 8 in Fig. 2) which permits control of pressures.

h. Each pump must be equipped with a check valve (valves 9 of Fig. 2) which prevents return flows through pumps.

ITEM 5: Temperature sensors, thermostats, and recorder

a. Two identical temperature sensors must be furnished. They shall consist of thermocouples or other suitable elements which respond to temperature changes of $\pm$ 1^0F over a range of temperatures from 32°F to 220°F. One temperature sensor shall be located at point B and the other one at point C of Plan 1. The sensors will be installed by the University.

b. The temperature sensors shall be connected to thermostatically controlled switches which cut off the power to the small pumps when the temperature exceeds the thermostat setting by 1° F and which switches the power on to the small pumps when the temperature at the sensor drops below 1° F of the setting of the thermostat.

c. The thermostat shall permit setting anywhere in a range from 32° to 200° F. The thermostats shall be located on the west side of the tunnel next to the location of the temperature sensors.

d. Also provided shall be a temperature read-out indicating the temperature at the location of the temperature sensor with an accuracy of ± 1° F. These read-outs shall be located on the main control panel (see Plan 1). The read-outs shall consist of a two-channel strip chart recorder and the necessary input control (amplifiers, etc. for sensor signal). The recorder shall provide a continuous recording of the sensor outputs. The chart reading can be in electrical units provided that a calibration chart is furnished which permits conversion of electrical units to units measured by sensors.

e. All thermostats, indicators, and temperature sensors shall be connected by color-coded wires which facilitate trouble shooting, replacing of faulty wires, and addition of other controls.

ITEM 6: Cooling coils

a. The coils which are located at Section A of the wind tunnel (Plan 1) shall provide sufficient cooling or heating area for satisfying the 8 design cases of Table 1.

b. They shall be finned or plain according to the choice of the contractor. The choice shall be based on the fact that a minimum pressure drop across the coils is most desirable.

c. The coils shall be made of materials which will withstand the corrosive action of the coolant chosen by the contractor. They shall not be affected by either hot or cold liquid flow, and construction shall be such that the expected temperature expansions or contractions do not damage any joints, connections or valves.

d. The coils shall be furnished in units which cover an area of 3' x 9' as shown in Fig. 1.

e. The coils shall be furnished with couplings and valves at the outlet to permit easy removal of the individual units.

f. The coil units shall be provided with attachments (e.g., hooks, eyes, bolts) which permit lifting them out of their position with a crane without causing damage to the tubes.

g. Provision shall be made for draining defrost water from the top coils to the bottom of the bank without danger that the drained water will form ice on any lower tubes or tube fins.

h. The coils shall be bolted laterally to angle irons as shown in detail A of Plan 1.

i. The need for a center beam as well as the design of such a beam shall be investigated by the contractor.

j. The tubes will be sufficiently stiff or clamped to prevent vibration from aerodynamic force.

ITEM 7: Coil manifolds

a. Four manifolds shall be provided on each end of the coils to permit supplying the coils as shown in Fig. 1.

b. The manifold outlets shall be equipped with valves which will be closed before removal of the coil units.

c. The manifolds shall be of sufficient size to permit uniform supply to each coil unit at maximum refrigeration or heating requirements (at maximum flow rates).

d. The manifolds shall be of a material which will withstand the corrosive action of the hot or cold liquid.

e. The manifolds shall be sufficiently insulated individually or together to prevent excessive heat losses or heat inflows.

ITEM 8: Pipes and pipe fittings

a. The pipes connecting refrigeration units, heating units, and coils shall be of sufficient size to permit maximum designed flow of coolant or heating fluid to reach the coils without excessive pressure losses.

b. The pipes shall be of a material to withstand the corrosive action of the hot or cold liquid.

c. Pipe fittings shall be supplied as necessary. They shall be of a material which does not deteriorate under the corrosive action of a coolant or hot liquid. They shall provide air tight and coolant tight joints everywhere.

ITEM 9: Valves

a. Eleven valves (valves 1 to 7 of Fig. 2) for main operation shall be supplied for the heating and cooling systems as well as a sufficient amount of small valves which control the flow in the coil units and which are placed between the coil manifolds and the coil banks.

b. The eleven control valves shall be of sufficient size to permit the operation as outlined in Table 1 and as described in Paragraphs 2.3 and 2.4. They shall be located as required by the systems shown in Fig. 2.

c. All control valves shall be of a material which will withstand the corrosive action of a cold or hot fluid.

d. Valves for each coil unit shall be provided in agreement with paragraph 2.2.

ITEM 10: Insulation

a. All manifolds, pipes, pipe fittings and valves shall be insulated sufficiently to prevent excessive heat loss or heat inflow to the hot liquid or coolant.

3. Humidification Control System

3.1 General description

The humidity control system consists of a humidity sensor and switch which is activated by the humidity sensor. This switch can be set like a thermostat and opens and closes a circuit which in turn opens and closes a valve in the pipeline supplying the spray nozzles. Pipeline and spray nozzles are to be of such dimensions as to raise the humidity of the air, when air is passed only once through the tunnel (open circuit), from 10 % relative humidity at 200° F to 95% relative humidity at 200°F at air speeds up to 10 feet per second in the 18'x 18' section. The flow of water can be controlled by a valve in the pipeline to the nozzles.

3.2 Specifications for humidification control system

The contractor shall supply and install (unless otherwise specified), under due consideration of applicable standards and accepted practices, with help of skilled personnel and by using best practical materials, the following items pertaining to the cooling, heating, and dehumidification systems. The design principles and design values outlined in the preceeding sections are to be adhered to.

ITEM 11: Spray nozzles

a. Spray nozzles shall be arranged on the wall of Station D in Plan 1. Spray will be directed generally normal to the direction of air flow.

b. The quantity of spray nozzles required shall be determined by the requirement that there must be a uniform distribution of moisture across Section D.

c. The size of the spray nozzles is determined by the requirement that it must be possible to raise the humidity of the open circuit air from 10% relative humidity at 200^0 F to 95% relative humidity at 200^0 F at air speeds up to 10 feet per second in the 18'x 18' section.

d. The size of spray droplets must be such that they will not settle to the floor before evaporating from a height of two feet or greater when the air speed is 1 foot per second in the 18'x 18' section and the relative humidity is 90%.

e. Spray nozzles shall be of a type which may be readily cleaned should stoppage occur.

ITEM 12: Spray Manifold

a. Manifolds shall be arranged in the walls of the wind tunnel in Section D to supply the spray nozzles.

b. The manifolds shall be of sufficient size to permit an essentially equal flow of water through each nozzle without requiring more pressure than standard supply pressure in the water main.

c. Manifold entrances will be provided with filters to prevent stoppage of nozzles and with valving to permit drainage and cleaning of the manifolds.

ITEM 13: Valves

a. The water line which supplies the spray nozzles shall be equipped with two valves. One valve (valve 1) shall be manually controlled to permit adjusting the mean discharge through the spray nozzles.

b. Valve 2 shall be an electrically controlled valve which closes when the humidity sensor indicates that the ambient humidity has risen more than 5% above a set humidity value and which opens as the humidity of the ambient air has fallen 5% below the desired humidity.

ITEM 14: Humidity control

a. The humidity control shall consist of a humidity sensor and an adjustable switch, both to be supplied by the contractor.

b. The humidity sensor is located at point B in Plan 1. It will be installed by the University. It shall be of such a type that it produces an electrical signal which varies with the humidity of the air. This signal shall be transmitted to a switch.

c. The switch shall be located on the west wall of the test section and shall permit setting of the humidity according to the contractor's choice--either over a continuous range or in steps of no more than 10% of relative humidity at 32^{0} F.

d. This switch activates the electric controlled valve (Item 13-c).

e. Also provided shall be a humidity indicator which indicates the humidity accurately within $\pm$ 5% of relative humidity at 32^{0} F. This indicator shall be located on the main control panel.

4. Heat Source and Sink

4.1 General description

The heat source and sink consists of a 40 feet long aluminum plate extending over the full width of the wind tunnel test section. The plate can be heated or cooled from below in a variable manner so that the surface temperature of the plate can be adjusted to a constant desired level at each air velocity. Provision for heating of the plate as well as measurement of local temperatures will be accomplished by systems designed and constructed at Colorado State University. Also designed and constructed at Colorado State University is the plate itself including the aluminum coolant ducts underneath the plate. (See Figure Number 5).

Only the manifolds and the control valves for establishment and maintaining cold temperatures of the plate form part of the specifications. The flow to the plate is supplied and returned through the four manifolds. The flow through the manifolds is controlled by two sets of valves. The first set of valves consists of one valve at the entrance to each supply manifold. These valves control the overall flow rate in each manifold.

The second set consists of valves which control the rate in each duct underneath the aluminum plate. Each of these ducts will be equipped with a separate valve. These valves are arranged on the west side of the wind tunnel test section, i.e., half of them are fastened to a supply manifold and half of them to a return manifold.

The layout of the manifold system is shown in Figs. 4 and 5. These figures contain the dimensions of all parts of the manifold system with the exception of those dimensions which depend on quantities to be specified by the contractor. According to this, a total of 2 main control valves are required for the manifolds, and 105 valves are required for the control of the flow in the aluminum conduits underneath the aluminum plate. The latter valves shall be of standard design with the exception of the stems which shall be long enough to reach the outside of the control panel (see Fig. 5).

The control procedure for the plate temperature is summarized in Table 2.

4.2 Coolant requirements

The coolant requirements have been computed for undiluted ethylene glycol. They have to be converted according to the coolant choice of the contractor.

During the period of maximum cooling for the cold plate, 360 cfm of ethylene glycol at 23^{0} F have to be supplied to the plate conduits at a pressure which is sufficient to conduct 4.0 cfm through each of the 1.25" x 1.25" conduits of 6 feet length. The total cooling capacity of the refrigeration system for this purpose will not exceed 25 tons. Therefore, only system 2 of the refrigeration systems need to be connected to the plate.

4.3 Specifications for manifold system

The contractor shall supply and install (unless otherwise specified), under due consideration of applicable standards and accepted practices, with help of skilled personnel and by using best practical materials, the following items pertaining to the cooling, heating, and dehumidification systems. The design principles and design values outlined in the preceeding sections are to be adhered to.

ITEM 15: Manifolds

a. The manifolds shall consist of suitable material to withstand any corrosive action of the coolant. The material of the manifolds and valves will be chosen to minimize galvanic action with the aluminum pipe.

b. The manifolds shall be of such sizes that flows through each plate conduit will be, with fully opened valves, not less than 4 cfm as specified above. They shall be insulated sufficiently for preventing excessive heat inflows.

c. The system shall contain 4 manifolds, two each for supplying and for returning the coolant. They will be arranged in such a fashion that the flow directions in successive conduits are alternated, as indicated in Fig. 4. The manifolds will be fastened to the supports of the aluminum plate.

ITEM 16: Control valves

a. Two control valves shall be supplied which control the flow to (and from) the manifolds from (and to) the refrigeration unit (valves 10 in Fig. 2). They shall be of same size as main supply lines to manifolds.

b. 105 1-1/4" valves shall be furnished of which 52 have a short stem, and 53 have a long stem in agreement with Fig. 5. The dimensions of the stems are to be determined by the manifold dimensions and the dimensions of the control panel as shown in Fig. 5.

c. The 105 control valves shall be equipped with hard rubber or plastic hand wheels of not more than 2" diameter.

d. The 105 control valves shall be fastened to the manifolds in an air tight, leak proof manner. Their other end shall be furnished with a flange which shall permit leak proof and air tight clamping or bolting to flanges connected to the pipes leading to the square conduits of the plate.

e. All valves shall be standard design and shall be made of materials which withstand the corrosive action of coolant or hot fluid and minimize galvanic action with the manifold material and the aluminum pipe.

APPENDIX

METEOROLOGY DEPARTMENT
U. S. Army Electronic Proving Ground
Fort Huachuca, Arizona

PERFORMANCE AND RELATED CONSTRUCTION REQUIREMENTS

1.0 SCOPE

This specification covers the performance requirements for the micro-meteorological wind tunnel facility at the Colorado State University, Fort Collins, Colorado.

2.0 APPLICABLE DOCUMENTS

3.0 REQUIREMENTS

3.1 Performance Characteristics

3.1.1 Aerodynamic Characteristics

3.1.1.1 Test Section. The basic unit shall consist of a recirculating closed system type wind tunnel with a test section having approximate internal dimensions of six feet wide, six feet high, and eighty feet long, consisting of ten test section units each eight feet in length. In order to maintain zero pressure gradient along the longitudinal axis of the test section, the longitudinal slope of the test section ceiling shall be adjustable for the entire length of the test section in order to compensate for the turbulent boundary layer thickness growth specified in 3.1.1.4. The ceiling shall be supported from above by adjustment screws. The internal surfaces of the walls and ceiling units shall be aerodynamically smooth. The floor of each test section unit shall be constructed so that it may be removed without disassembly. This shall permit ease in installing heated or cooled boundaries or boundaries having a desired roughness. The three downstream test section units shall have thermopane windows which are mounted in the wall units flush with the inside wall of the tunnel. The lower edge of each window shall not be higher than the top surface of the tunnel floor and shall extend at least two feet above the tunnel floor level. All windows shall be designed so that they may be easily opened to permit access to the interior working area.

3.1.1.2 Ambient Velocity

The drive motor shall be a direct current motor installed within the propeller-drive motor chamber at the exhaust end of the wind tunnel test section. Air movement through the wind tunnel shall be accomplished by a variable pitch propeller driven by the drive motor. The power installation shall consist of a motor-generator power supply; adequate wiring, switches, and protective devices; meters to monitor drive motor and propeller operations; and control circuitry to insure steady flow or permit controlled unsteady flow. The ambient velocity variability within the test section shall not exceed plus or minus two percent of the velocity setting for steady flow at the entrance test section unit. Continuous, stepless speed control in the velocity range of one meter per second to 30 meters per second shall be provided for the ambient stream within the test section. Excepting the boundary layer regions, the ambient velocity variation across the entrance test section unit cross-section shall not exceed plus or minus two percent of the center velocity.

3.1.1.3 Ambient Turbulence Level

The entrance unit of the test section shall be connected to a contraction section having a contraction ratio of nine to one and the contraction profile of the floor, walls, and ceiling of this section shall consist of two cubic parabolas joined together with consistent slopes at the inflection point of the profile in accordance with the design criteria of 2.4. The entrance of the contraction section shall be connected to a settling chamber which is provided with slots so that screens may be introduced into the entrance of the settling chamber. The screens shall reduce the turbulence intensity of the air entering the test section to 0.1 percent or less. To avoid turbulence shedding by the screen wire, the screen wire diameter shall be restricted in diameter in accordance with criteria established in 2.2 for the maximum ambient velocity of the settling chamber. The settling chamber shall be connected to the propeller-drive motor chamber by a suitable return duct. The return duct shall be designed with due caution to insure a minimum of turbulence generation in the recirculating air; all corners shall be provided with suitable turning vanes.

3.1.1.4 Turbulent Boundary Layer

The tunnel shall be so designed that the turbulent boundary layer in the last downwind test section unit of the wind tunnel shall be up to two feet in thickness at an ambient velocity of two meters per second with an aerodynamically smooth boundary surface. The boundary layer shall be up to three feet in thickness with an aerodynamically rough boundary surface.

3.1.2 Thermodynamic Characteristics

3.1.2.1 Insulation

The basic unit shall be provided with insulation externally covering all walls, floors, and ceilings with the exception of the windows specified in 3.1.1.1. Insulation conductivity shall not be more than 0.07 British Thermal Units per square foot-hour for a one degree Fahrenheit temperature difference between tunnel wall and external wall. That portion of the basic unit which is at any time exposed to direct sunlight shall have a covering of reflecting material over the insulation. The basic unit shall be designed to prevent air leakage or exchange into or out of the return duct, settling chamber, and contraction section and to minimize leakage in the test section.

3.1.2.2 Ambient Temperature

The return duct shall be equipped with heat exchangers for heating and cooling the air within the basic unit. The cooling exchanger shall be operated by a refrigeration system which is located outside of the basic unit. The heat exchangers shall be designed for high efficiency with a minimum of turbulence generation. The heating unit shall be capable of raising and maintaining the air within the basic unit at a temperature of 50 degrees centigrade above the average temperature outside the basic unit. The cooling unit shall be capable of lowering in two hours and maintaining the air within the basic unit at a temperature of 20 degrees centigrade below the average temperature outside the basic unit with a power consumption of the drive motor at seventy-five kilowatts and the steady temperature of the air in the basic unit not lower than 0 degree centigrade. Automatic thermostatic control of the heating and cooling facilities shall be provided. The thermostatic control shall maintain steady ambient temperature of the air within the basic unit. For steady temperature conditions, the ambient temperature variability at the entrance unit of the test section shall not be greater than plus or minus two degrees centigrade for the temperature setting. Excepting the boundary layer regions, the ambient temperature variation across the entrance test section unit cross-section shall not exceed plus or minus two degrees centigrade.

3.1.2.3 Ambient Humidity

The return duct shall be equipped with a water spray system which is capable of adding a fine spray of water into the air within the basic unit for humidification. The spray unit shall be located up stream from the heat exchangers. Removal of water vapor shall be performed by the cooling exchanger specified in 3.1.2.2. A further requirement for the cooling exchanger specified in 3.1.2.2 is that it shall be designed so that it may be continuously defrosted while operating. The humidification unit shall be capable of raising and maintaining the relative humidity of the air within the basic unit to a relative humidity of ninety-five percent. The cooling exchanger shall be capable of drying the air to a dewpoint of minus five degrees centigrade. Automatic humidity control shall maintain steady ambient humidity of the air within the basic unit. For steady humidity and temperature conditions, the ambient humidity variability at the entrance unit of the test section shall not be greater than plus or minus five percent relative humidity for the humidity setting. Excepting the boundary layer regions, the ambient humidity variation across the entrance test section unit cross-section shall not be greater than plus or minus five percent relative humidity. The basic unit shall be so designated that liquid spray from the humidifier is not introduced into the test section.

3.1.2.4. Boundary Heat Source

The downstream portion of the test section shall be provided with a plane, smooth, heated floor which can be readily removed or interchanged with other floor units. The heated floor shall consist of separate units each having the length of the test section units (8 ft). The heated floor shall consist of sufficient units so that the thermal boundary layer developed shall be of the same thickness as the turbulent boundary layer in the last downstream unit of the test section. The heated floor units shall consist of plane, smooth, thick (1/2 inch or greater) plates of copper or aluminum heated from below by electrical heating coils. The heating coils shall be distributed so that the boundary surface temperature along the entire length and width of the heated floor is uniform. The boundary surface temperature variation shall not be greater than plus or minus two degrees centigrade. The heating units shall have sufficient power to raise and maintain the boundary surface temperature of the heated floor units at 100 degrees centigrade above the ambient temperature when the ambient temperature is 50 degrees centigrade, the temperature outside the basic unit is 25 degrees centigrade and the ambient velocity is 10 meters per second with aerodynamically smooth boundary. The heating units shall be insulated to minimize heat loss other than to the heated floor plates. Heat loss shall not exceed 5 percent of the heat output. The heat generation shall be continuously variable from zero to maximum heat output. Meters shall be provided to monitor the power consumption of the heating wires.

3.1.2.5 Boundary Heat Sink

The downstream portion of the test section shall be provided with a plane, smooth, cooled floor which can be readily removed or interchanged with other floor units. The cooled floor shall consist of separate units each having the length of the test section units (8 ft). The cooled floor shall consist of sufficient units so that the thermal boundary layer developed shall be of the same thickness as the turbulent boundary layer in the last downstream unit of the test section. The cooled floor units shall consist of plane, smooth, thick (1/2 inch or greater) plates of copper or aluminum cooled from below. The cooling shall be distributed so that the boundary surface temperature along the entire length and width of the cooled floor is uniform. The boundary surface temperature variation shall not exceed plus or minus four degrees centigrade. The cooling unit shall have sufficient power to lower and maintain the boundary surface temperature of the cooled floor units at 25 degrees centigrade below the ambient temperature when the ambient velocity is two meters per second over an aerodynamically smooth boundary. The cooling unit shall be insulated to minimize heat gain other than from the cooled floor unit plates. Heat gain from other sources shall not be greater than five percent of the total cooling power. The cooling power shall be continuously variable from zero to the maximum cooling power. Instrumentation shall be provided to monitor the heat transfer of the cooling units.