Chapter 1 – Basic Cooling and Air Conditioning Systems

EXPERIMENT 1.3 – OPERATIONAL PRINCIPLES AND MATERIALS

Name	Class/Period	Date

1. Objectives:

At the end of this experiment session, you will be able to:

- Understand what cooling materials (refrigerant) are.
- Explain the cooling materials characteristics.
- Understand the usage of the cooling materials.
- Understand the correlation between the cooling materials and the environment.
- Explain the cooling materials control devices.
- Explain the function of the metering devices.

2. Equipment Required:

- Main Platform Unit
- Professional Air Conditioning Panel

3. Discussion:

The cooling system should lower the temperature and specific humidity of the air flowing through it. To do that, the system must have an object capable of remaining at a lower temperature from the air temperature for a long period of time.

The cooling cycle purpose is to allow the existence of this object.

We have seen that liquid can boil at any temperature depending upon its pressure. The boiling temperature of any pressured substances differ from one another.

Liquid, which boils at low temperature, is a good object for removing heat.

During boiling, the liquid absorbs heat from its surroundings only if the surroundings temperature is higher than the liquid boiling temperature.

The energy the liquid needs to boil is taken from its surroundings. This energy is the latent heat needed for changing the liquid state to gas state. The energy required for changing a mass unit state is higher than the energy required for changing the same mass unit temperature.

For this reason, it is preferable to use the state change principle in order to remove heat from a certain environment.

The existing cooling materials meet the requirement for boiling in low temperatures. Many of the cooling materials boil in temperature lower than 0o Fahrenheit in a normal atmospheric pressure.

4. Discussion: **Cooling materials**

Cooling materials were chosen due to their ability to boil at low temperatures. There are a number of cooling materials in the industry. They are numbered and all of them have the prefix R (Refrigerant).

There are two main groups of cooling materials:

1. The first group includes the following cooling materials:
   - R11, R12, R22, R113, R114, R500

   These cooling materials numbers (except R500) were determined by the following method:

   The right first digit equals the number of the molecule's Fluoro atoms.

   The right second digit is bigger by one from the number of the molecule's hydrogen atoms.

   The right third digit is smaller by one from the number of the molecule's carbon atoms.

2. The second group includes the following cooling materials:
   - Ammonia (NH_3) – R717
   - Water (H_2O) – R718
   - Air – R729
   - Carbon dioxide (CO_2) – R744

   The ammonia molecule is comprised of a sodium atom and three hydrogen atoms.

   The water molecule is comprised of an oxygen atom and two hydrogen atoms.

   The carbon dioxide molecule is comprised of a carbon atom and two oxygen atoms.

   The air is composed from several materials and does not have a chemical formula.

5. Discussion: **The cooling materials characteristics**

- Boiling temperature in atmospheric pressure:

R11	–	+23.7°C
R12	–	–29.7°C
R22	–	–40.7°C
R113	–	+47.5°C
R114	–	+3.6°C
R500	–	–33.3°C
Ammonia	–	–33.3°C
Water	–	+100°C
Air	–	–194.5°C
Carbon dioxide	–	–78.5°C

The boiling temperature should be low so that the liquid substance absorbs heat during its evaporation. Additionally, the operation pressure corresponding to temperature should be above the atmospheric pressure in case a hole in the pipe system causes leakage of the cooling material and air or water will not infiltrate the system.

- Freezing temperature in atmospheric pressure:

R11	–	–111.1°C
R12	–	–157.7°C
R22	–	–160.0°C
R113	–	–35.0°C
R114	–	–93.8°C
R500	–	–158.9°C
Ammonia	–	–77.7°C
Water	–	0.0°C
Air	–	–194.5°C
Carbon dioxide	–	–56.5°C

To maintain a constant flow, the cooling material should be at a higher temperature than its freezing temperature at a certain pressure. Cooling materials have very low freezing temperatures.

Gas leakage pace differs from material to material and is dependent upon a straight ratio of the material pressure. The material pressure is in an inverted ratio to the material molecule weight. The heavier the molecule, the lower the pressure the material at low temperatures will be.

- When a gas has a high specific weight, it can receive more latent heat during the evaporation process because with the same volume, a larger amount of heat is received. This is why this kind of gas flow can be lessened than a gas with a lower specific weight can.

  A common production unit in air-conditioning and cooling systems is cooling ton.

  A cooling ton is the energy supplied to a ton of ice in 0ºC in order to melt it in 24 hours. The cooling ton is marked by TR.

$$1TR = 12{,}000\ BTU/H$$

- The cooling materials are not flammable, and cannot cause explosion except for the ammonia (when it is mixed with air in a 16-25% concentration).
- The cooling materials toxicity can cause suffocation when there is a great concentration of them in the air (above 30% of the room's volume).
- One must avoid lighting a fire near cooling materials because it creates a toxic gas called Phosgene. This toxic gas has a very pungent smell, which serves as a warning.
- Smell – all the cooling materials (except the ammonia) are odorless.
- Oil solubility – oil needed for the compressor operation flows in the system with the cooling material. An important characteristic of the cooling materials is their ability to dissolve with the oil and flow as a mixture.
- Each cooling material is stored in a container with a different color for identification purposes.

6. Discussion: **Usage of the main cooling materials**

- **R11** – designated for especially big cooling or air-conditioning systems. Suitable for centrifugal compressors. Another use for this cooling material is cleaning the gas from the inside in systems, which work with other cooling materials. Because of the ozone problem, it is used minimally today.

- **Carbon dioxide** – this cooling material was in use in the past, but today, because the high compressor power it needs, and the high compressing pressure it operates under, its use is limited to low temperature cooling systems.

- **Water** – water usually is used in big systems as an intermediate material between the air and another cooling material. Water is an inexpensive material with good heat transfer characteristics.

- **Ammonia** – mainly used in big professional cooling facilities for low temperatures. Its high toxicity prevents its use in human occupant air-conditioning systems.

- **R12** – used in a wide variety of facilities for cooling. Its operation pressures are convenient and it requires a relatively low compressor power for every cooling ton. The R12 is replaced today with the R134a and devices with R12 are not manufactured any more.

- **R22** – used in a wide variety of facilities for cooling and air-conditioning. This cooling material is still inexpensive and available, and has good cooling productions. It is mainly used for air-conditioning and cooling chambers.

The R134, R404 and R22 are the most common cooling materials.

7. Discussion: **Environmental hazard in cooling materials**

It has been proven in laboratory experiments that some of the cooling materials cause the ozone layer protecting earth to dilute, and harm the ability of heat transfer from Earth to outer space, thus causing the Earth to warm up.

These cooling materials contain only carbon, chlorine and Fluoro atoms. In other words, R11, R12, R114, and R113.

This environmental situation brought on a resolution to gradually reduce the production of these cooling materials until their complete production cancellation in 2000.

Due to these cooling materials production cancellation, new cooling materials were developed with better performances, which will not harm the ozone layer and will not cause the Earth warming up.

R12 was replaced by R134a, and R11 was replaced by R123.

The R134a molecule is composed of two carbon atoms, four Fluoro atoms, and two hydrogen atoms. This cooling material does not include chlorine, thus it does not have any effect on the ozone layer. Its influence on the Earth warming up is smaller by 11 than the R12 influence.

The R123 cooling material indeed includes chlorine, but its affect on the ozone layer is smaller by 62 than the R11. Its influence on the Earth warming up is smaller by 53 that the R11.

8. Discussion: The cooling control methods

The cooling systems of today are automatically operated. Measurements devices were developed to control the flow of the cooling liquid in the evaporator. These devices also control the electrical motors, which operate the system.

The cooling control can be divided to three basic levels:

- Control based on pressures changes.
- Control based on temperature changes.
- Control based on volume or quantity changes.

A combination of these three levels is in use.

Automatic control of the cooling and motors is required in order to maintain the desired temperature in the cooled area.

9. Discussion: Metering devices

Metering devices are connected between the condenser's battery and the evaporator. Their functions are:

1) To separate the high-pressure side from the low-pressure side in the cooling circle.
2) To supply the required amount of cooling material according to the desired load to the evaporator.
To guard the superheating cooling material coming out from the evaporator into the compressor.

9.1. Capillary (CAP.) Tube:

The capillary tube is made of copper, and has a very small internal diameter in contrast to other tubes. The cooling material encounters a barrier of high resistance, and this causes the liquid pressure to lower while it flows through the capillary tube.

The capillary tube is designed to lower the cooling liquid pressure by the same measure that the compressor raised it during the compression process.

The pressure drop on the tube depends on:

1. The internal diameter of the tube.
2. The tube length.
3. The flow speed.
4. The cooling material specific weight.
5. The friction coefficient between the cooling material and the tube.

The pressure drop on a capillary tube (or on any other tube) is calculated according to the following formula:

$$\Delta P = r \cdot \frac{L}{D} \cdot \frac{V^2}{2^r g} \cdot \gamma$$

ΔP – Pressure drop in the tube.

f – Friction coefficient between the cooling material external layer flowing in the tube and the tube's internal side. This coefficient depends on the tube's surface quality, and on the flow speed.

L – Tube's length.

D – Tube's diameter.

V – Flow speed of the cooling material.

g – Earth's gravity acceleration.

γ – Specific weight of the cooling material.

The capillary tube is used in domestic devices (refrigerators, window air-conditioners, and divided air-conditioners), and medium cooling devices.

Advantages: Simple, low cost and no parts, which can cause faults.

Disadvantages: suitable only for small and medium productions; sensitive to blockings because of is small diameter; vulnerable; and because the pressure drop on it is constant, the amounts of flow cannot be regulated.

10. Discussion: **The automatic expansion valve (TEV)**

The expansion valve fulfills a triple function in the cooling circuit:

- It releases the pressure on the refrigerant which is in a liquid state on its way to the evaporator. This enables its expansion while reducing its temperature to the lowest value in the cooling circuit, a degree that enables efficient heat exchange with the air in the refrigerated area.
- It determines the refrigerant flow intensity through the cooling circuit, in accordance with the inputted temperature request to cool in the refrigerated area.
- It ensures that the liquid will not reach the compressor.

While the air cools down in the refrigerated area, the cooling output from the evaporator must be reduced, otherwise it will cause ice formation on the evaporator pipes, preventing the efficient function of the air-conditioning system. The reduction of the cooling output in this case is done by means of the expansion valve. It controls the flow rate of the refrigerant through the evaporator affecting the output of the air-conditioning system.

Thermostatic expansion valve (which is also used also in the training panel):

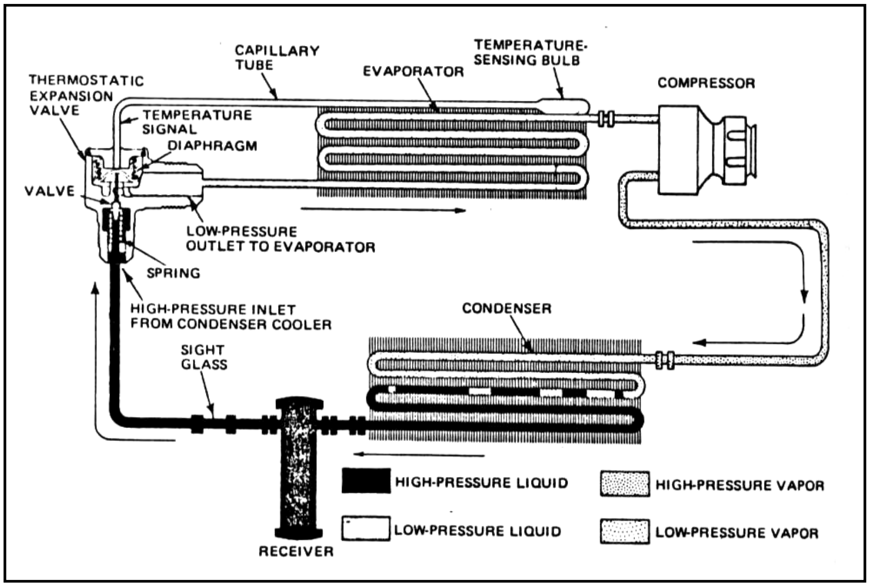


Figure 1-20 Air-Conditioning Circuit with an Expansion Valve

The refrigerant fluid arrives to the expansion valve while it is very hot and under high pressure. The refrigerant comes out from the other side of the expansion valve at the lowest temperature existant in the cooling circuit.

During the expansion process, the refrigerant begins to evaporate such that when the refrigerant enters the evaporator, it is already partly in a gas state.

10.1. Adjust of the thermostatic expansion valve:

The thermostatic expansion valve setting determines the amount of superheat in the refrigerant gas. Superheat is the gas temperature, which is above the temperature given by the pressure and temperature chart for specific pressure. Most valves are set to 10°F superheat. The superheat determines the amount of liquid refrigerant mixed in the returned gas. Too little superheat will cause the liquid refrigerant to damage the compressor. Too much superheat will cause poor evaporator coil performance and compressor overheating.

Warning: Usually, the valve is not to be adjusted. Unprofessional adjustment will harm its performance.

10.2. Thermostatic expansion valve sizing:

The size of the expansion valve is very important. Its size is adapted to the system's size (the system's production).

Every expansion valve is adapted to a wide range of productions specifications, and in order to adapt it to a specific production, a special nozzle is inserted to the gas input of the expansion valve.

There is a wide variety of nozzles, which come in different sizes. Each size fits various valves and productions.

10.3. Thermostatic expansion valve advantages:

The first advantage would be the capability of the thermostatic expansion valve to regulate refrigerant flow over a wide range of load conditions. The second advantage would be its ability to shut off refrigerant flow when the compressor stops.

Because the valve can increase or decrease refrigerant flow according to load, it can raise or lower the amount of energy used by the compressor.

11. Discussion: **Suction pressure valve**

Many systems use valves composed of a diaphragm, which stabilize the pressure. These kinds of valves are needed in systems where the evaporator works at various temperatures.

12. Discussion: **Reversing valve**

Reversing valve is a component of a heat pump that reverses the refrigerant's direction of flow, allowing the heat pump to switch from cooling to heating or heating to cooling.

This subject is explained in experiment 1.6.

13. Procedure:

Step 1: Check that the PROFESSIONAL AIR CONDITIONING PANEL is properly installed on the refrigeration and air-conditioning general system MAIN PLATFORM UNIT according to the instructions described in the book's preface.

Step 2: Check that the MAIN PLATFORM UNIT MONITOR and PROGRAM switches are at OFF position.

A ground leakage relay, a semi-automatic switch, and a main power switch are installed in a main power box located on the rear panel.

Step 3: Connect the MAIN PLATFORM UNIT power supply cable to the Mains.

Step 4: Check that the high voltage ground leakage relay and the semi-automatic switch are ON.

Step 5: Set the Auto/Manual switch (located on the bottom left of the simulator) to the Manual position.

Step 6: Turn ON the main POWER switch located on the main power box on the rear panel.

Step 7: Turn ON the monitor power switch.

Step 8: The FAULT display should display the number 00. If not, use the keys above the FAULT display to display the number 00 (no fault condition) on the FAULT 7-segment display and press the ENTER key beneath this display.

Step 9: The STATE display should display the number 00 (no operation program).

Step 10: On the LCD display you should find the following table:

V1	V2	V3	V4	V5	V6	V7	RV	CM	OF

Check that the two taps on the flexible pipes are open.

In this experiment we shall implement 4 methods of controlling the air-conditioning system - thermostat control, pump down control, low pressure pressurestat control and compression pressure control.

The first method is based on temperature control. The second method is based on temperature and pressure control. We shall implement them in TEV mode.

We will implement low pressure pressurestat control in capillary mode.

TEV mode:

Step 11: Press 11 on the STATE.

Changing the STATE number does not start the operating program (even after pressing the ENTER key).

The STATE number after pressing the ENTER key only displays the required operating program and state.

Step 12: Lower the PROGRAM switch and raise it.

The TEV mode states are 11-16.

Note: You can move from one TEV state to another without lowering and raising the PROGRAM switch. If you lower and raise the PROGRAM switch, the system will undergo a delay for safety operation.

The TEV programs are:

State 11 – TEV operation with °C display.

State 12 – TEV operation with °F display.

State 13 – TEV operation with graphic display.

State 14 – TEV operation with °C display and thermal load.

State 15 – TEV operation with °F display and thermal load.

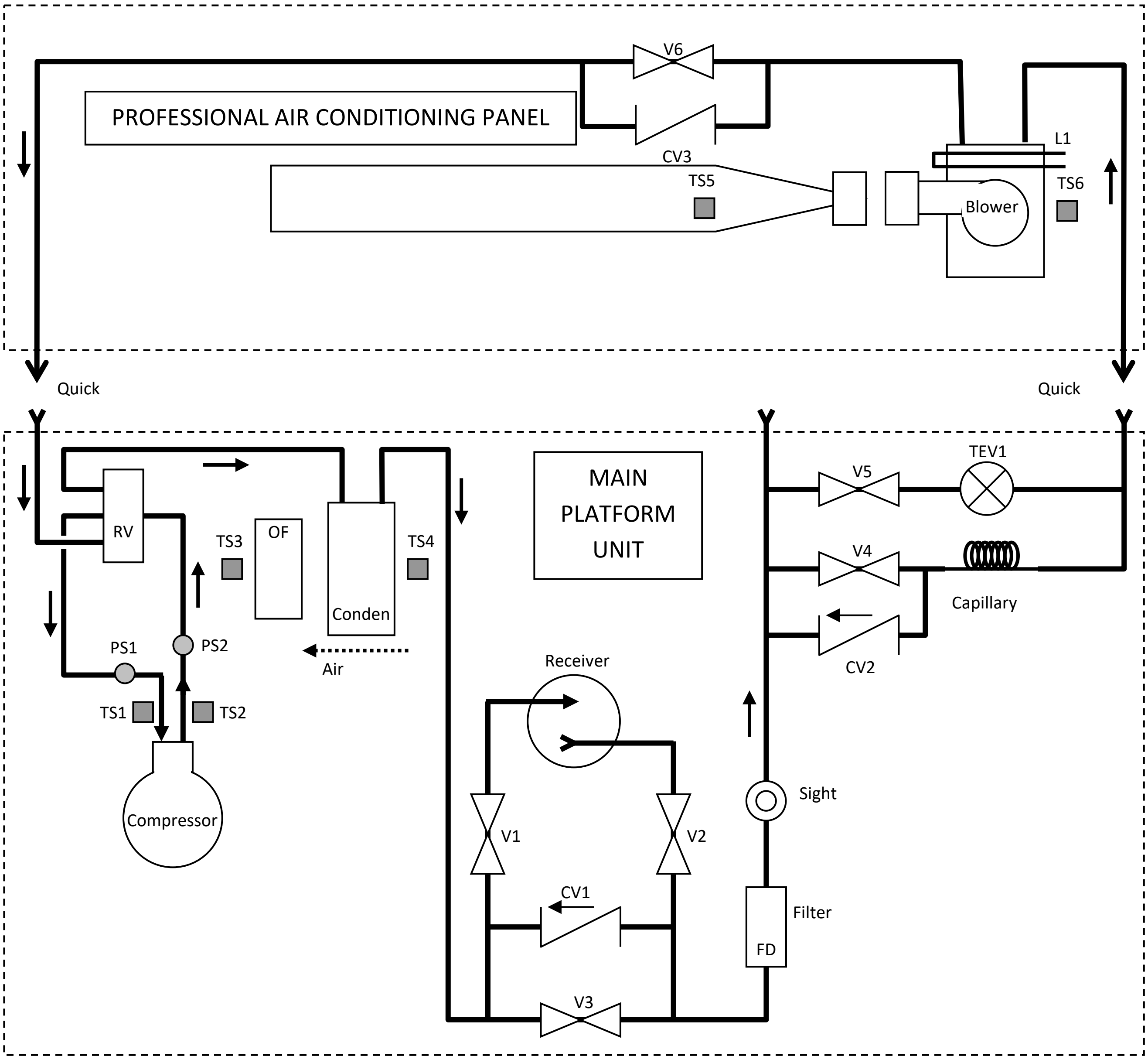
State 16 – TEV operation with graphic display and thermal load.

Step 13: On the LCD display you should find the following table:

V1	V2	V3	V4	V5	V6	V7	RV	CM	OF
ON	ON			ON	ON			ON	ON

If "on" (lowercase) appears on the CM and OF columns, it means that the compressor is in a 3 minutes delay state before it starts to work. This delay protects the compressor.

Step 14: The refrigerant path is marked on the following circuit.



Step 15: The LCD also displays the system pressures and temperature as follows:

LP	HP	T1	T2	T3	T4	T5	T6	T7	T8

LP – Low Pressure (the suction pressure measured by PS1)

HP – High Pressure (the compression pressure measured by PS2)

T1 – The compressor inlet temperature (measured by TS1)

T2 – The compressor outlet temperature (measured by TS2)

T3 – The condenser outlet air temperature (measured by TS3)

T4 – The condenser inlet air temperature (measured by TS4)

T5 – The evaporator outlet air temperature (measured by TS5)

T6 – The evaporator inlet air temperature (the cooling chamber temperature measured by TS6)

T7 – Not relevant to this panel

T8 – Not relevant to this panel

Identify the sensors in the drawing and in the system.

Step 16: Another table that appears on the LCD display is the control parameters:

S1	D1	S2	D2	SP	PD	E1	L1	E2	RT
20°C	5°C					LO			

S1 – Room temperature setup

D1 – Room temperature difference

Thermostat control:

The setup temperature is the required temperature. When the cooling chamber temperature goes below this temperature, the air-conditioning system should stop cooling and this is done by stopping the compressor.

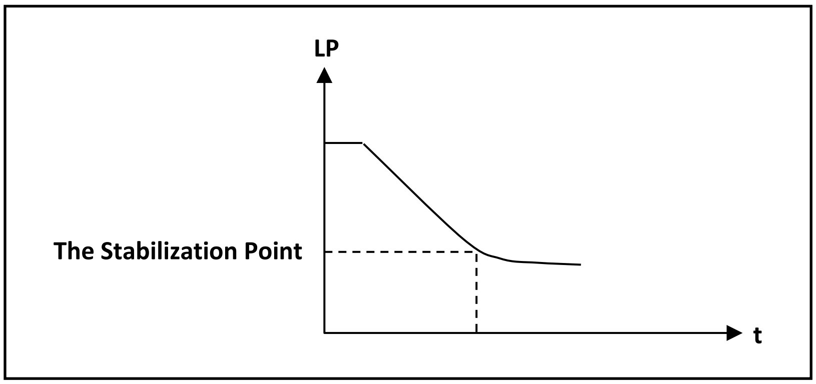
The compressor turns ON when the cooling chamber temperature is above S1 + D1. D1 is determined in order to avoid the system to oscillate.

There is a linear relationship between the temperature and pressure. This is why we can control the cooling chamber temperature according to the system low pressure or the system high pressure. This subject will be described later.

The TEV mode is controlled by temperature and this is why a dash appears in the pressure squares.

Identify the system's default values of S1 and D1.

Step 17: Immediately after operating the air-conditioning, the suction pressure should be high and going down while the system is cooled according to the following graph.



Observe this sight glass and check that there are no bubbles.

Step 18: Change the STATE no. to 12 and press ENTER.

This state does not change the system's operation; it only changes the display from °C to °F.

The S1 value changes to 68°F and the D1 to 9°F.

Observe that.

Change the STATE no. to 11 and press ENTER.

Step 19: The cooling chamber temperature should continue to go down even after the LP stabilized.

Observe that.

Step 20: The chamber temperature T6 goes down as long as the system is cooling (the compressor works).

In the 11-16 experiment states the air-conditioning's control is according to the temperature as thermostat method.

The compressor should turn OFF when the chamber temperature reaches the S1 (Setup Point) and should turn ON when the chamber temperature goes over S1 + D1.

The default value of S1 is 20°C (68°F), the default value of D1 is 5°C (9°F).

Check that.

Step 21: See what happens when the cooling chamber temperature reaches the S1 point.

Step 22: Record the pressures and temperatures.

Step 23: Wait until the compressor turns ON again.

Step 24: Record the pressures and temperatures.

Step 25: The evaporator speed can be changed by the '*' key.

Press the '*' key and check that the evaporator fan (E1) changes to HI.

Step 26: Wait until the compressor turns OFF.

Step 27: Record the pressures and temperatures.

Step 28: Wait until the compressor turns ON.

Step 29: Record the pressures and temperatures.

Step 30: Press the '*' key again and check that E1 is changed into 'LO'.

Step 31: Fill in the following table with the stabilization point's values of the two setup points.

No.	Comp.	E1	S1	D1	LP	HP	T1	T2	T3	T4	T5	T6
1.	ON	LO										
2.	OFF	LO										
3.	ON	HI										
4.	OFF	HI										

Step 32: The system at 11-16 states allows you to change the ST value in a certain range.

Key in the number 10 (if you are in ^{o}C) or 46 (if you are in ^{o}F) and key '#'.

Step 33: Change the state no. to 11 or 12 accordingly.

Step 34: Wait until the compressor stops working.

Step 35: Record the pressures and temperatures.

Step 36: Wait until the compressor turns ON.

Step 37: Record the pressures and temperatures.

Step 38: Change the fan speed to High.

Step 39: Wait until the compressor turns OFF.

Step 40: Record the pressures and temperatures.

Step 41: Wait until the compressor turns ON.

Step 42: Record the pressures and temperatures.

Step 43: Fill in the following table with the stabilization point's values of the two setup points:

No.	**Comp.**	**E1**	**S1**	**D1**	**LP**	**HP**	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**
1.	ON	LO										
2.	OFF	LO										
3.	ON	HI										
4.	OFF	HI										

Pump down control:

The pump down control is based on temperature and pressure control.

When the cooled chamber temperature reaches the setup point temperature, the control system does not stop the compressor and the thermostat fan operation, but closes valve V5 only.

Closing V5 causes the suction pressure to drop and when the LP (the suction pressure) goes below its setup value the compressor stops.

This control method takes care that the suction pressure is low when the compressor stops.

The TEV mode has other three states – 17, 18 and 19.

Step 44: Change the STATE number to 17 (for ^{o}C) or 18 (for ^{o}F) and press ENTER.

The control table should change to the following:

S1	D1	S2	D2	SP	PD	E1	L1	E2	RT
20^{o}C	5^{o}C			20	17				

The control values of this table cannot be changed.

Step 45: The chamber temperature T6 goes down as long as the system is cooling (the compressor works).

Valve V5 should turn OFF when the chamber temperature reaches the S1 (Setup Point).

The default value of S1 is 20^{o}C (68^{o}F), the default value of D1 is 5^{o}C (9^{o}F).

The compressor continues to work until LP goes below the SP point.

Step 46: See what happens when the cooling chamber temperature reaches the S1 point.

Step 47: Record the pressures and temperatures.

Step 48: Wait until the compressor turns OFF.

Step 49: Record the pressures and temperatures.

Step 50: When the T6 goes above S1 + D1, V5 opens and supplies gas to the evaporator. As a result, the pressure rises, and when it is higher than SP, the compressor starts working.

Wait until they turn ON.

Step 51: Record the pressures and temperatures.

Step 52: Fill in the following table with the stabilization point's values of the two setup points.

No.	V5	Comp.	S1	D1	LP	HP	T1	T2	T3	T4	T5	T6
1.	ON	ON										
2.	OFF	ON										
3.	OFF	OFF										
4.	ON	ON										

Step 53: Change STATE to 19 and press ENTER.

Step 54: Observe the system behavior graphically.

Step 55: Change the STATE no. to 00 and press ENTER.

Lower the PROGRAM switch and raise it.

All the devices should shut OFF.

Step 56: Wait about 5 minutes.

Low pressure pressurestat control:

As explained, there is a linear relationship between temperature and pressure.

Controlling temperature can be done by controlling the pressure.

At states 21-26 the control is done according to LP (Low pressure) value.

Step 57: Change the STATE no. to 21 and press ENTER.

Step 58: Lower the PROGRAM switch and raise it.

The capillary mode states are 21-26.

The capillary programs are:

State 21 – capillary operation with °C display.

State 22 – capillary operation with °F display.

State 23 – capillary operation with graphic display.

State 24 – capillary operation with °C display and thermal load.

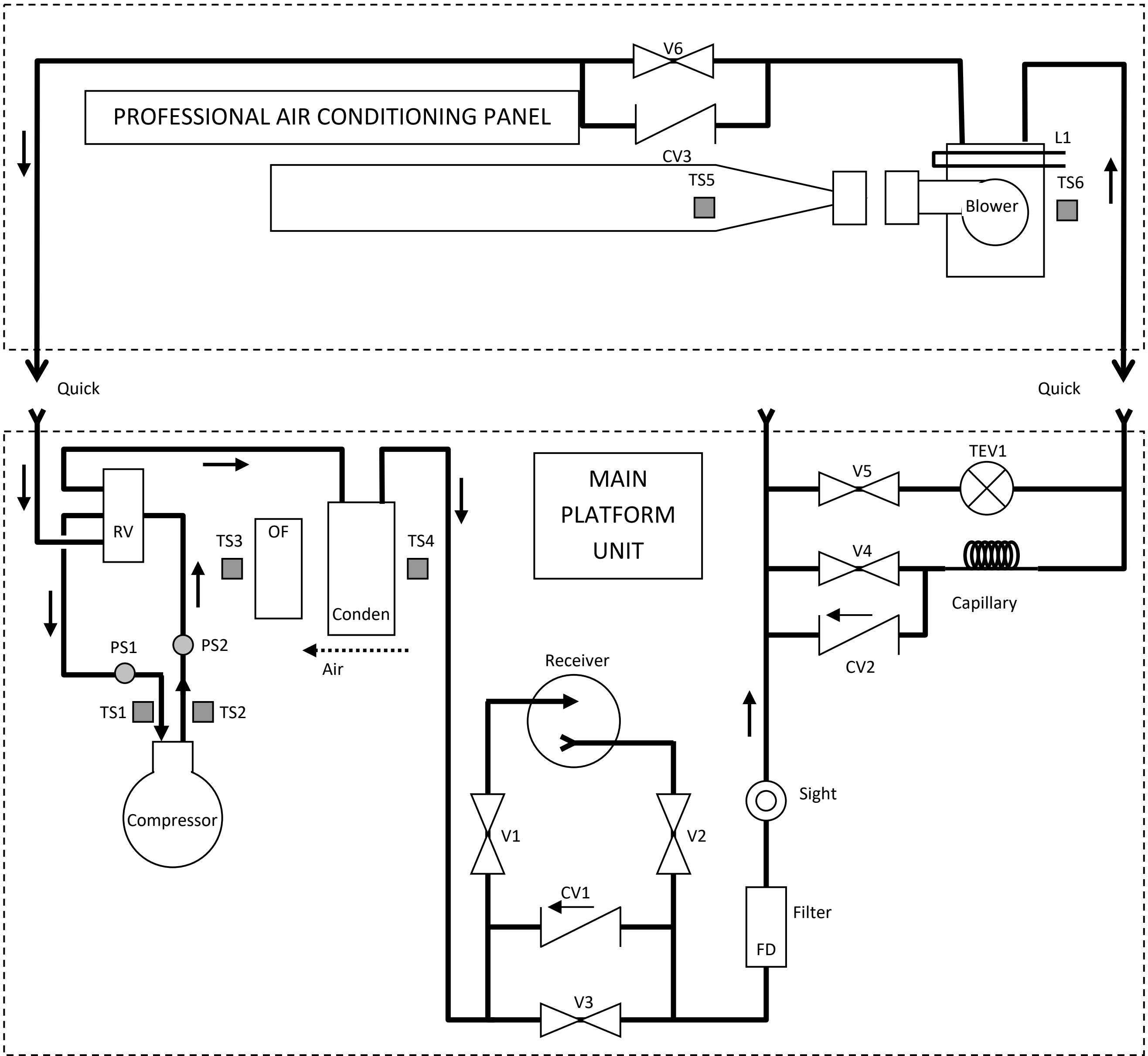
State 25 – capillary operation with °F display and thermal load.

State 26 – capillary operation with graphic display.

Step 59: On the LCD display you should find the following table:

V1	V2	V3	V4	V5	V6	V7	RV	CM	OF
		ON	ON		ON			ON	ON

Step 60: The refrigerant path is marked on the following circuit.



Step 61: The sensors table is the same as the TEV experiment.

LP	HP	T1	T2	T3	T4	T5	T6	T7	T8

Step 62: The control table is a little different. At this experiment the control is made according to the low pressure.

The table is as follows:

S1	D1	S2	D2	SP	PD	E1	L1	E2	RT
				33	17	LO			

Step 63: Change the STATE no. to 22 and press ENTER.

This state does not change the system's operation; it only changes the display from °C to °F.

Observe that.

Step 64: Observe the temperature and pressure values and wait for the system to stabilize.

Step 65: When SP is at a stable point, record the temperature and pressure values at the stabilization point.

The cooling chamber temperature should continue to go down.

Step 66: Change the STATE no. to 23 and press ENTER.

This state does not change the system's operation; it only changes the display to graphic display.

The monitor samples and displays the LP and T6 every 0.5 minute and displays them graphically on the screen.

Observe that.

Step 67: Wait until the compressor stops working.

Step 68: Record the pressures and temperatures.

Step 69: Open the cooling chamber window.

Step 70: Wait until the compressor turns ON.

Step 71: Record the pressures and temperatures.

Step 72: Keying a number followed by '#' changes the SP value. The monitor allows changing it in within a certain safety range.

Key the number 20 and press '#'.

Step 73: Check that the SP is changed to 20.

Step 74: Wait until the compressor stops working.

Step 75: Record the pressures and temperatures.

Step 76: Open the cooling chamber window.

Step 77: Wait until the compressor turns ON.

Step 78: Record the pressures and temperatures.