Guidance page for practical work 14: Air conditioning

1) Objectives of the practical work

The objective is to study two air conditioning cycles (one for summer and one for winter), and show how to model them realistically with Thermoptim.

Note immediately that pictograms to represent the changes undergone by a moist gas do not exist in Thermoptim, so that there will be no diagram associated with these models. In these examples, as we cannot use the diagram editor, we will work directly in the simulator environment.

This document is an excerpt of the guidance page with complete results, which is reserved for teachers. For this reason, the numbering of figures is flawed.

2) References

M. DUMINIL *Air Humide*, Techniques de l'Ingénieur, Traité Mécanique et chaleur, B 2 220.

AICVF *Conception des installations de climatisation, et de conditionnement de l'air*, Collection des guides de l'AICVF, PYC Edition, Paris, octobre 1999.

R. CASARI *Cahier Technique, données théoriques et technologiques, conduite de projets, mallette pédagogique Conditionnement d'air,* septembre 1992, Paris, Documentation interne, École des Mines de Paris.

Mitchell J. W. & Braun J. E., Principles of HVAC in Buildings, John Wiley and Sons, Inc, January 2012.

T. Agami Reddy, Psychrometrics and comfort, Handbook of Heating, Ventilation, and Air Conditioning, (Edited by J.F. Kreider), CRC Press, Boca Raton, 2001, ISBN 0-8493-9584-4

A. Rabl, P. Curtiss, Energy calculations – Building loads, Handbook of Heating, Ventilation, and Air Conditioning, (Edited by J.F. Kreider), CRC Press, Boca Raton, 2001, ISBN 0-8493-9584-4.

3) Main practical work

3.1 Setting out

The design of an air conditioning system comprises a series of distinct steps:

- climatic conditions of reference that will be used to calculate the enthalpy and water loads must be first determined. In practice, it is based on climatic data published by national meteorological services, which are eventually corrected as indicated below. The values to take into account are not the extreme conditions but those likely to be reached or exceeded a few days per year on average. For winter, corrections must be made to temperatures at high altitude sites (-1 °C every 200 m) and cities (+1 to 2 °C depending on the size of the metropolitan area), and an estimate of relative humidities can be obtained simply (100% along the coast or a lake, 90% elsewhere);
- environmental conditions must then be defined (T. Agami Reddy, 2001). For specific industrial applications, refer to the information of AICVF Guides in France or ASHRAE in the U.S. For comfort cooling, it should be noted that most healthy people do not feel any noticeable difference as long as the relative humidity is between 30 and 60% and the temperature is below 25 °C. As a first approximation we can therefore choose for summer a temperature of 25 °C and a relative humidity of 60%, and for winter temperatures of 19 or 20 °C and a relative humidity of 30%;
- once these values are chosen, it becomes possible to calculate loads. Depending on countries, calculations are slightly differently expressed: in the U.S. for example, sensible and latent loads are considered while in France we talk of enthalpy and water loads (AICVF, 1999). This simply means that in the first case, water to be extracted is directly converted in energy terms, while in the second it is expressed in kg/s. Detailed calculation of heat loss from a building are outside the scope of this document: you should refer to the AICVF Guides (1999) or methods proposed by CSTB or ASHRAE (A. Rabl, P. Curtiss, 2001). Sensible (or

enthalpy) load Qs is given by equation (21.1.1), in which φ_p represents losses through the walls, φ_i losses by air infiltration (which should certainly not be confused with those due to air renewal that are implicitly taken into account by the calculation method), φ_s solar gains and P the set of internal gains due to occupants, lighting, appliances, machinery, office equipment etc.

$$Q = \varphi_p + \varphi_i + \varphi_s + P \qquad (3.1)$$

- the supply or condition line can then be determined by:

With French notations:

Water conservation: $\dot{m}_{eau} = \dot{m}_{air}\,(w_{su} - w_1)$

enthalpy conservation: $\dot{m}_{air}\,(q'_{su} - q'_1) = \dot{Q} + \dot{m}_{eau}\,h_{eau}(t_1)$

et en éliminant le débit d'air on obtient le rapport de pente γ :

$$\gamma = \frac{\Delta q'}{\Delta w} = \frac{\dot{Q} + \dot{m}_{eau} h_{eau}(t_1)}{\dot{m}_{eau}} \qquad (3.2)$$

With US notations:

$$SHR = \frac{\dot{Q}_s}{\dot{Q}_s + \dot{Q}_l}$$

- In the psychrometric chart, the condition line is the line of slope SHR or γ passing through the point representing the desired comfort conditions. Each point of this line corresponds to a different supply flow-rate. The actual flow-rate value depends on various factors, such as the maximum allowable temperature difference to avoid any inconvenience (usually 6 to 12 °C according to the technique used), or the rate of mixing required (generally between 3 and 20 volumes/hour) to ensure good uniformity without drafts;
- Once the supply point is determined, it remains to choose an air treatment for bringing a mixture of outdoor air and indoor air in this state. The recirculation rate depends on hygiene constraints. The more important it is, the higher the energy expenditure will be. The following examples show how basic treatments can be combined to form a proper air conditioning unit. Note that in first approximation the fan heats pumped air by about 1 °C. In winter this means less heating need, and in summer greater cooling need.

There are many possible air conditioning cycles, and their presentation is beyond the scope of this document (Mitchell & Braun, 2012). We will, therefore, present only two examples of typical installations of summer cooling and winter heating.

The equations governing moist air processes were established in section 7.8 of Part 2. Thermoptim has screens available to address them.

3.2 Summer air conditioning

The facility that we are going to study corresponds to the cooling of a large building like an airport located in a hot and humid climate.

The problem data are as follows: we seek to maintain the internal ambience of the building at a temperature of 24 °C (297.15 K) and a relative humidity equal to 50%. External climatic conditions are: temperature equal to 30 °C (303.15 K), and relative humidity of 80%. It is necessary to remove external and internal thermal loads of 162.6 kW, as well as a quantity of water equal to 60 kg/h, i.e. 0.01667 kg/s.

Knowing that, for sanitary and comfort reasons, the supply temperature must not be less than 14 °C (287.15 K), and that the recycled air proportion must not exceed 70%, the purpose of the exercise is to determine:

- supply conditions;
- a way of processing of the outdoor air/recycled air mix.

A possible treatment of the mixed air is to cool it, condensing water in excess to obtain specific humidity corresponding to the supply conditions, then warm it to supply temperature. There are others, but we will present this one here.

3.2.1 Principle of calculations

The first step is to determine the supply conditions, which Thermoptim can do. The calculation leads to the following: a flow rate of 12 kg/s, specific humidity w = 0.0079, and temperature t = 14 °C.

The second step calculates the state of the mixed air. This yields specific humidity w = 0.013, and temperature t = 25.8 °C (point 1).

The air conditioning unit chosen requires cooling mixed air in the dehumidifier to w = 0.0079, then reheat it at t = 14 °C.

The cooling coil chosen has a surface temperature of 7 °C. A perfect theoretical cooling in an infinite surface coil would lead to cool the wet mixture at the temperature of the coil in the saturated state (we have added a fictitious point 0 to represent it). A real process is characterized taking as reference the theoretical cooling to point 0 and introducing either the cooling coil effectiveness ε (here 75%) or its bypass factor b such as b = 1 – ε (here 25%). Its calculation shows that the mixture is then cooled at 11.7 °C (point 2).

The heater allows it to be brought to the desired supply temperature (point S).

When you run Thermoptim, the simulator screen is shown (Figure 3.1):

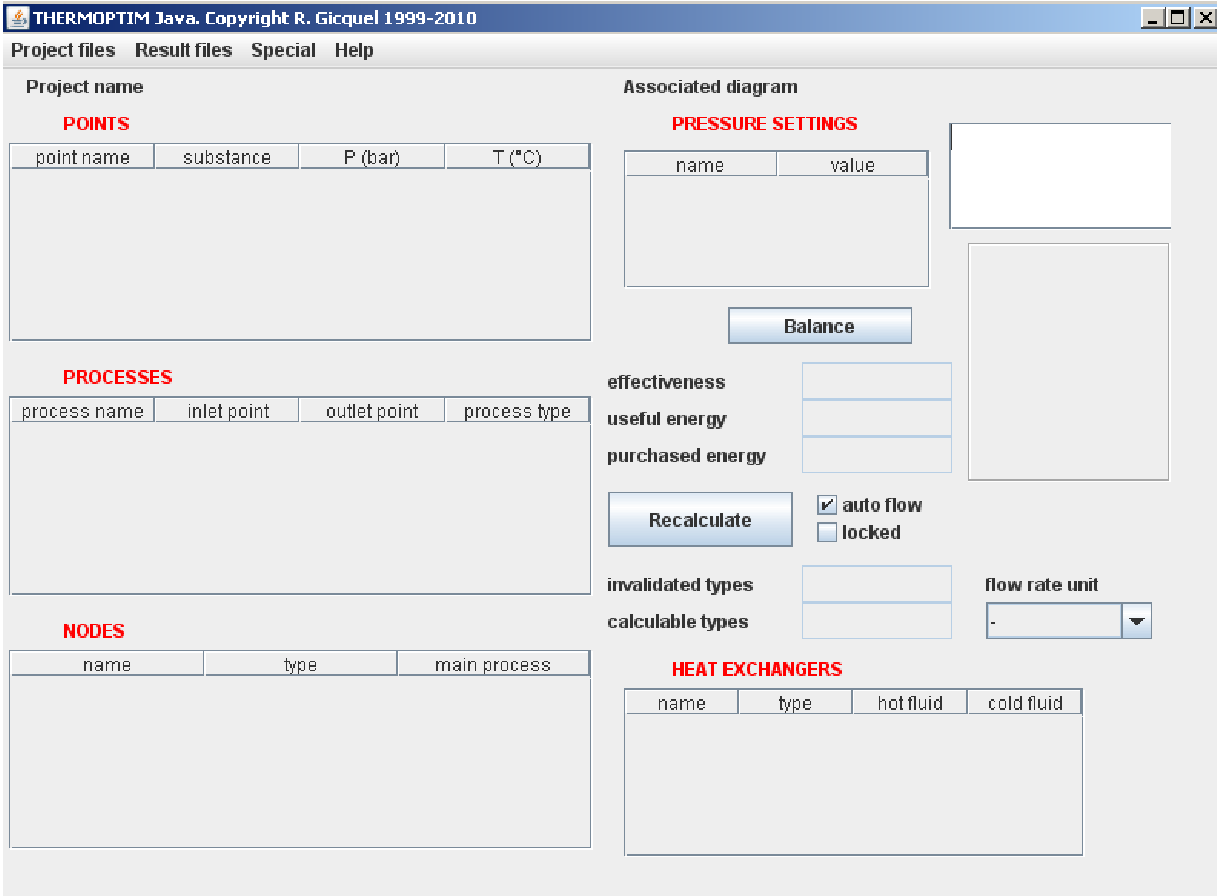

Figure 3.1: Thermoptim simulator screen

Start by naming the new project, calling such "air conditioning". To do this, type Ctrl N or use the line "New Project" of menu Project Files, then enter the name.

In what follows, all points share the same dry gas, air, and are at the same pressure, 1 atm.

3.2.2 Supply conditions

Start by creating two points entitled "indoor air" and "outdoor air", by setting their respective temperatures and relative humidities, and a third point, called "supply", with the temperature 14 ° C.

To do this, double-click in the heading of the points table, enter the point and the substance names. For the latter, you can either select from the list of the existing substances, which appears when you double-click the field name, or enter it directly yourself. In the latter case, it is necessary for you to type a newline after the name, so that Thermoptim know that you have finished entering it.

Then enter the values of temperature and pressure, and calculate the point, then select the "wet gas" tab, and enter either the specific humidity w if known, or the relative humidity epsi. As appropriate, then click on "set w" or "set epsi", so that the moist properties of the point are calculated.

For the first point, for example, you get the result in Figure 3.2.

Then, create a supply water vapor / gas mixture process, connecting points "indoor air" and "supply". Enter the values of the thermal and water loads in the appropriate framework, with a negative sign because they are to be removed, and choose « Calculate the supply conditions, the supply temperature being known ».

The process is calculated. The supply flow rate is determined, as well as the point "supply" humidity:

The "supply" process screen is updated (figure 3.4)

3.2.3 Properties of the mix (outdoor air / recycled air)

The first step of the air processing consists of calculating the properties of the mix (outdoor air / recycled air), which is then cooled. The calculation of the mixture takes place in a particular node, called moist mixer. Like all nodes, its definition has two parts: the main vein and branches.

Start by creating the moist cooling process to which it is connected. To do this, create two new points, called "mixed air" and "cooled air", connect the upstream and downstream of the process, which becomes the main vein. Then build two processes-points associated with points "outside air" (flow rate 0.3) and "indoor air" (flow rate 0.7), and connect them to the mixer as branches.

Once built the mixer, you can calculate it (Figure 3.5).

The state of the point that you get output of the mixer is given in Figure 3.6.

3.2.4 Air treatment

The challenge now is how to treat the mixed air (25.8 ° C, w = 0.013) to get the supply conditions (14 ° C, w = 0.00792).

One solution is to cool it until its specific humidity is equal to that of the supply air, and then to warm it to obtain the desired temperature.

Set w = 0.00792 as specific humidity of the cooled air, then choose in the "cooling" process a realistic cooling coil surface temperature (eg 7 ° C), take the supply flow rate as calculated previously, select the appropriate method of calculation for THERMOPTIM to search the coil effectiveness required, and calculate the process.

You get the temperature of the cooled air and the effectiveness of the cooling coil.

To determine the heating to be provided, it only remains to connect the point "air cooled" to point "supply" by a heating -type moist process of the same flow-rate.

3.2.5 Plotting the cycle

Return to the simulator screen, and open the psychrometric chart through the Chart / Simulator interface.

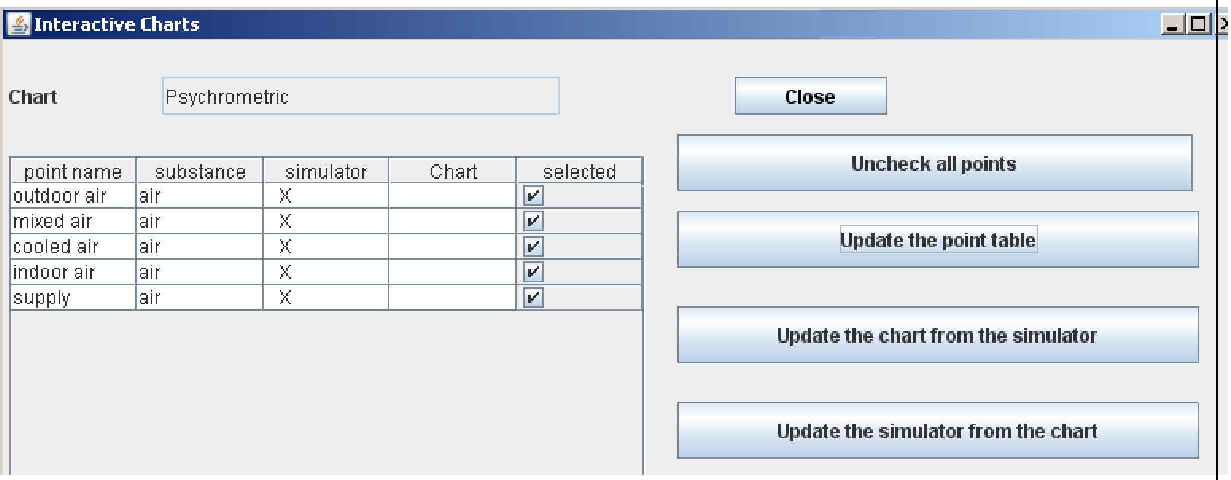

Figure 3.9: Interface

Update the table of points, then the chart from the simulator. Finally, select "Points connected" in the menu "Cycle". The cycle plot on the psychrometric chart is given in Figure 3.10.

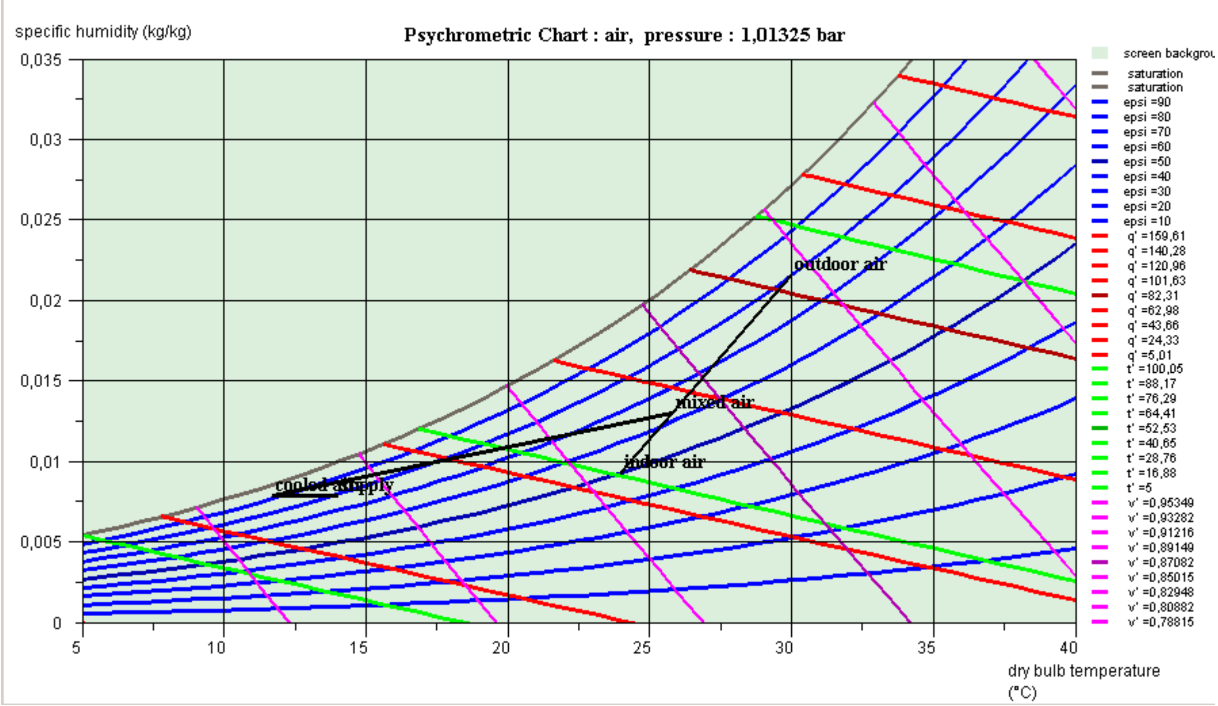

Figure 3.10: Summer air conditioning

The air processing cycle is shown in the chart, the mixed air being as required on the mixing line that connects the inside air and outside air.

3.3 Winter air conditioning

The facility that we will study corresponds to the heating of a large building like a bank, located in a cool, moist climate. For this, we have a ventilation system that allows air to blow in different parts of the building. For reasons of hygiene it is necessary to renew the air, but some can be recycled, however, which reduces heating needs.

So we recycle some of the indoor air that is mixed with outside air, previously preheated to prevent condensation on the ducts or jamming of registers. This mixture must be treated before being injected into the ventilation system so that its state corresponds to the supply conditions. These are calculated so that the external thermal loads are compensated by taking into account internal inputs. It is assumed that the water load is zero and air temperature is 27 °C.

A possible treatment of the mixed air is to humidify it adiabatically until its specific humidity corresponds to the desired supply conditions and then to warm it up at the desired air temperature. There are others, but this will be presented here.

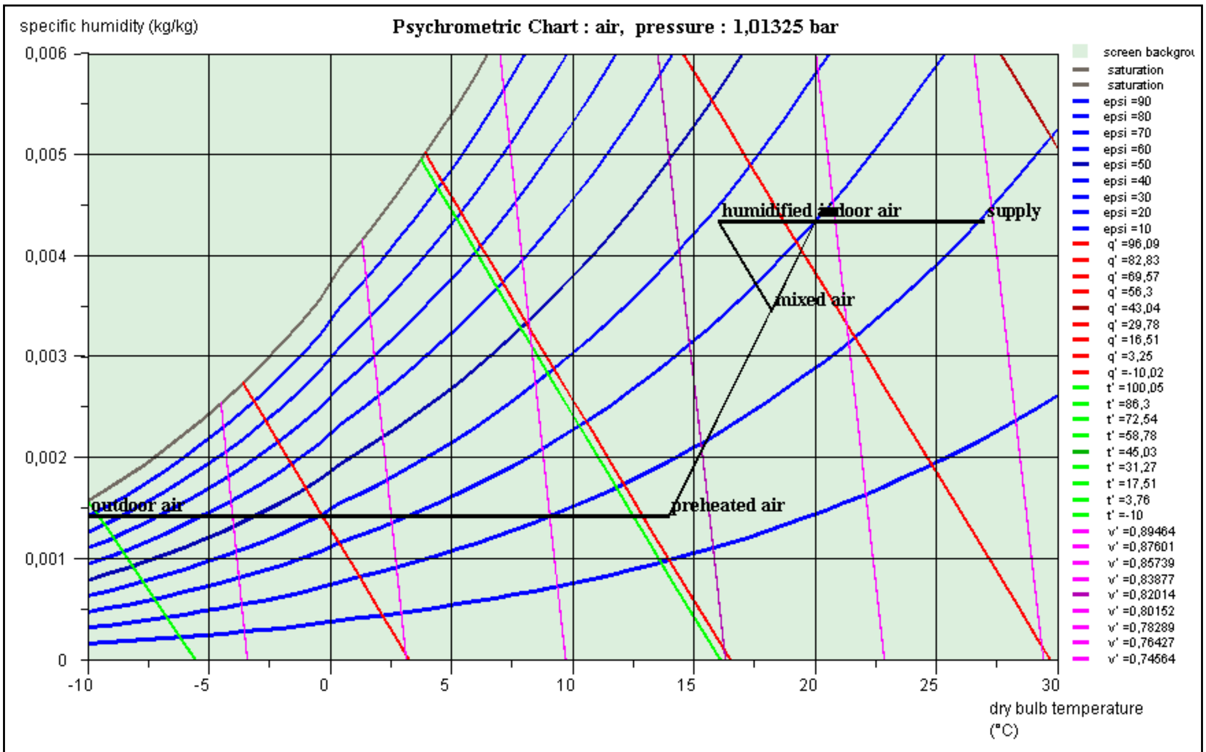

Figure 3.11: Winter air conditioning

The problem data are as follows: we seek to maintain the atmosphere inside the building at a temperature of 20 °C and a relative humidity of 30%. External climatic conditions are: temperature equal to -10 °C and relative humidity of 90%. We must provide a heat input of 100 kW off ventilation, but no water. To avoid parasite condensation, fresh air is preheated at 14 °C (point 1).

Knowing that, for reasons of hygiene and comfort, the proportion of return air should not exceed 70%, the purpose of the exercise is to determine:
- supply conditions;
- a way of processing of the outdoor air/recycled air mix.

We have neglected here the blowing fan air warming (about 1°C).

The first two steps are similar to those of the previous example. The calculation of supply conditions leads to the following: a flow-rate of 14.1 kg/s, specific humidity w = 0.0433, and temperature t = 27 °C.

The specific humidity of outside air is w = 0.0014. It is preheated at 14 °C (point 1). For indoor recycled air w = 0.0043. Given the rate of recirculation, humidity is here w = 0.0346, and temperature 18.2 °C (point 2).

It is therefore necessary to moisten the mixture at the supply humidity, for example in an adiabatic humidifier. Its effectiveness is calculated: 23.7%, the temperature of the moist mixture being 16.2 °C (point 3). Recall that an adiabatic humidification is achieved by spraying water to form a rain sprinkling the air, the heat needed to vaporize the water being supplied by air. As is done to cool a moist mixture, the reference is a theoretical humidifying leading the air to saturation, the real wetting being characterized by its effectiveness ε.

A heat addition for heating the mixture at 27 °C is necessary (point S).

The plot of the cycle on the psychrometric charts is given in Figure 3.11.