A Simulation Model for the Exploitation of Geothermal Energy for a Greenhouse in the Viterbo Province

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Abstract
The increasing demand of energy for industrial production and urban facilities asks for new strategies for energy sources .
In recent years an important problem is to have some energy storage, production and consumption which fulfill in some environment friendly expectations. Much more attention has been recently devoted to renewable energies.
Among them energy production from geothermal sources has becoming one of the most attracting topics for engineering applications. Ground coupled heat transfer might give an efficient energy for well-built construction.
At a few meters below the earth's surface the underground maintains a constant temperature in a approximation through the year allowing to withdraw heat in winter to warm up the habitat and to surrender heat during summer to refresh it.
Exploiting this principle, heat exchange is carried out with heat pumps compound to vertical ground heat exchanger tubes that allows the heating and cooling of the buildings utilising a single plant installation. This procedure ensure a high degree of productivity, with a moderate electric power requirement compared to performances.
The aim of this work is the simulation with the TRNSYS program of the geothermal plant needed for air conditioning a greenhouse in Viterbo. The model realized has allowed to set up the plant for the heat exchange with the thermal basin, defining the technical elements and verifying the exploitation of geothermal system in a greenhouse in the outskirts of Viterbo.

Keywords: heat exchange, TRNSYS, heat pumps

Introduction

Geothermal (ground-source) heat pumps (GHP) are one of the fastest growing applications of renewable energy in the world, with annual increases of 10% in about 30 countries over the past 10 years (Lund, Sanner, Rybach, Curtis, Hellström, 2004). In Europe, like some other southern countries, Italy has been one of the last countries to find interest in ground source heat pumps; the reasons should probably be found in some aspects:
– mild climate, because of the Mediterranean closed sea, with minimum temperatures normally not less than -3°C and maximum temperature not more than 30-35°C;
– different approaches to the heating solutions; in Italy there is a habit to natural gas furnaces, because there is a huge pipe network, that supply the gas at low cost, nearly to everyone; only isolated villages or houses in the countryside, isles, hills or mountains, are not reached by the gas net and they usually adopt propane gas or oil, as fuels for furnaces;
– a general culture that erroneously identifies electricity for heating with electric resistance, with an immediate callback to high running costs;
– low interest in renewable energies. Geotherm srl Earth Energy Systems was founded in the year 2000 after some years of groundwork and planning. The inspiration for the firm arrived

by chance from a short article with the description of heating and cooling systems in the USA, that were "plugged to earth" (Maritan and Panizzolo, 2008).

Today, the Italian geothermal heat pumps market is still a niche one, where people show good interest but where different technical approaches, competitors and designers introduce a quite wide number of solutions, plugged to the ground: these solutions are sometimes standard and well tested, sometimes not tested or well designed; the effect is that the number of not working systems or saturated ground loops are growing too, with bad influence to the entire market. The second effect is that the final ground source customer is now often confused because he/she is pushed by companies or thermal engineers to follow a way and the opposite of it.

The use of greenhouses for growing plants is widely used in Italy. The design and implementation of greenhouses is done without the study of energy exchanges between the external environment inside the greenhouse. Climatic conditions are evaluated only on the plant species planted without verifying the construction parameters of the greenhouse or efficiency of air conditioning systems.

Greenhouses are the primary use of geothermal energy in the agribusiness industry. Most greenhouse operators estimate that using geothermal resources instead of traditional energy sources saves about 80% of fuel costs — about 5% to 8% of total operating costs. The relatively rural location of most geothermal resources also offers advantages, including clean air, few disease problems, clean water, a stable workforce, and, often, low taxes. This paper verifies the efficiency geothermal plan with TRNSYS 16.

Materials and methods

Geothermal heating and cooling

Geothermal heating and cooling systems provide space conditioning, heating, cooling, and humidity control. They may also provide water heating , either to supplement or replace conventional water heaters. Geothermal heating and cooling systems work by moving heat, rather than by converting chemical energy to heat like in a furnace. Every geothermal heating and cooling systems has three major subsystems or parts: a geothermal heat pump to move heat between the building and the fluid in the earth connection, an earth connection for transferring heat between its fluid and the earth, and a distribution subsystem for delivering heating or cooling to the greenhouses.

The geothermal heat pump is packaged in a single cabinet, and includes the compressor, loop-to-refrigerant heat exchanger, and controls. Systems that distribute heat using ducted air also contain the air handler, duct fan, filter, refrigerant-to-air heat exchanger, and condensate removal system for air conditioning. For home installations, the geothermal heat pump cabinet is usually located in a basement, attic, or closet. In commercial installations, it may be hung above a suspended ceiling or installed as a self-contained console.

Most greenhouses geothermal systems use conventional ductwork to distribute hot or cold air and to provide humidity control (a few systems use water-to-water heat pumps with one or more fan-coil units, baseboard radiators, or under-floor circulating pipes). Properly sized, constructed, and sealed ducts are essential to maintain system efficiency. Ducts must be well insulated and, whenever possible, located inside of the building's thermal envelope (conditioned space). Geothermal heating and cooling systems for large commercial buildings, such as schools and offices, often use a different arrangement. Multiple heat pumps (perhaps one for each classroom or office) are attached to the same earth connection by a loop inside the building. In this way, each area of the building can be individually controlled. The heat pumps on the sunny side of the building may provide cooling while those on the shady side are providing heat. This arrangement is very economical, as heat is merely being transferred from one area of the building to another, with the earth connection serving as the heat source or heat sink only for the difference between the building's heating and cooling needs.

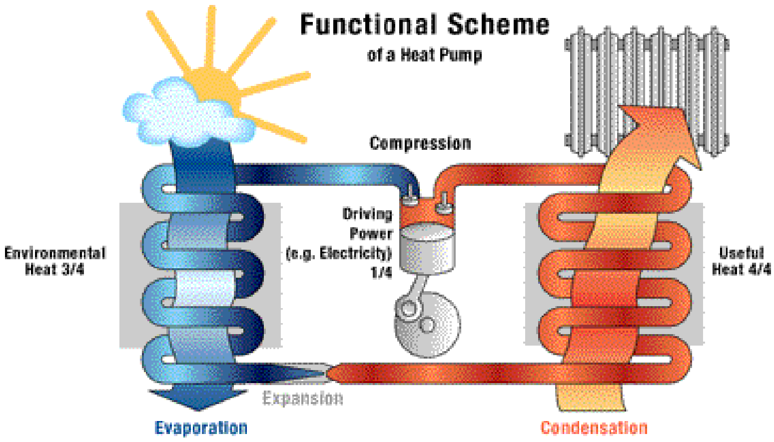

Figure 1. Heat pump scheme

The key to the efficiency of a GSHP is the Coefficient of Performance: the "C.O.P.". In spite of the first law of thermodynamics, which tells us that energy can neither be created nor destroyed, a GSHP in a good installation can yield up to four units of heat for each unit of electricity consumed. Naturally the heat pump is not creating this energy, but merely separating a medium temperature from the ground into warmth (which can be used for heating) and cold (which can be returned to the ground). The C.O.P. will vary with each installation, but the lower is the output temperature to the heat distribution system the higher the C.O.P. will be. If an output temperature of 60°C is needed to heat radiators the C.O.P. is likely to fall to level of only 2.5. If the heat distribution is to a well designed underfloor heating system that works well at an output temperature of 40°C then the C.O.P. can rise to a level of 4. The input temperature is also critical to the C.O.P. of the heat pump. The higher the input temperature from the ground, the lower the amount of work needed from the heat pump, the higher the C.O.P. will be. In fact, the critical factor is the "uplift" between the source temperature and the output temperature. Normally a GSHP starts with a ground temperature of about 10°C: this is the natural temperature of the ground at a depth of six metres. This temperature of around 10°C will be found across Great Britain, summer or winter, unless unusual conditions apply. The reason is that heat only moves very slowly in the ground. Unusual conditions will be found where a heat pump is in action: as a heat pump draws heat from the ground the ground temperature will fall from the natural level of 10°C to a lower level (which depends on the amount of heat drawn from the ground and the volume of ground from which it is extracted). As the ground temperature gets colder the heat pump will have more work to do to deliver the output temperature required for heating. In these conditions the C.O.P. of the heat pump will fall below the rule of thumb figure, often given, of 4. If asked to extract heat from ground which is too cold, the ground source heat pump will "Lock Up". Normally a GSHP starts with a ground temperature of about 10°C: this is the natural temperature of the ground at a depth of six metres. This temperature of around 10°C will be found across Great Britain, summer or winter, unless unusual conditions apply. The reason is that heat only moves very slowly in the ground. Unusual conditions will be found where a heat pump is in action: as a heat pump draws heat from the ground the ground temperature will fall from the natural level of 10°C to a lower level (which depends on the amount of heat

drawn from the ground and the volume of ground from which it is extracted). As the ground temperature gets colder the heat pump will have more work to do to deliver the output temperature required for heating. In these conditions the COP of the heat pump will fall below the rule of thumb figure, often given, of 4. If asked to extract heat from ground which is too cold, the ground source heat pump will "lock up".The C.O.P. is critical because, although a heat pump can be efficient, electricity is more expensive than gas. If we do not get a high C.O.P. from the heat pump it could be cheaper to use a gas boiler for heating. In terms of carbon saving a heat pump releases no CO_2 on site, but you should consider the CO_2 emitted at the power stations to create the electricity to use.

Geothermal Greenhouse model with TRNSYS

The TRNSYS is a software commonly used to simulate transient heat transfer for the design and control of power systems using renewable energy sources. Another frequent use of the software is now on the energy certification for homes, offices, shops, restaurants and industries. In this sense the present work is an example of using the software for agricultural systems. The greenhouse considered is a steel structure prefabricated construction, used for growing flowers and plants and with glass cover.

The outline of the project is as follows:

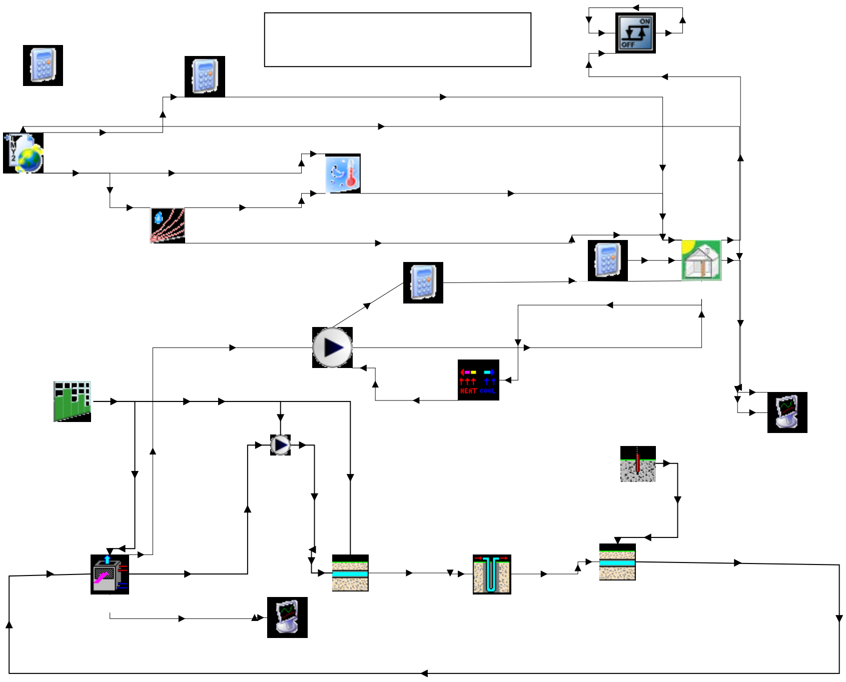

Figure 2. Geothermal greenhouses project

Where icons mean:

- Turn: building orientation converter
- Weather data: weather data reader
- Radiation: solar radiation converter for surfaces
- Psychrometrics: psychrometrics computer
- Sky temp.: CPU Sky Temperature
- Nat. Vent.1: natural ventilation controller
- Building: Greenhouse (Type 56)

- Cooling: cooling temperature set
- Temp. Control: heating and cooling controller (on/off)
- Airchanges: heating and cooling airchanges computer
- Pump, Pump-2: conditioning pump and geothermal system pump
- Heat Pump: heat pump
- On/off Function: geothermal system controller (on/off)
- Soil Temperature: soil thermal probe
- Pipe, Pipe-2, Pipe-3: geothermal system pipes and heat exchangers
- Temperature: temperature charts creator
- C.O.P.: C.O.P. charts creator.

The approach of the model was carried out by using the program TRNSYS Simulation Studio. It was done starting with the path led to the construction of a multizone building, which is divided into multiple steps where the user enters the data of the building and its location in space. The data required by the software at this stage will be used for the automatic construction of the project and its connections between the components. For setting-up the project there is also the source of meteorological data that will be used in the simulation. This is indeed a link with the Type 109 (Weather Data Processor) selected from the meteorological station of Viterbo. As for the greenhouse, we have chosen the climate system geothermal, with radiant ground.

Mathematical description of the geothermal model

In this section is described in detail the matematical modelling of the geothermal plant. It will be also shown how they can be regulate by the user, who must fit single components by connecting all the time-dependent variables, and describing fixed parameters.

Ground temperature profile

This model calculate the vertical temperature distribution of the ground given the mean ground surface temperature for the year, the amplitude of the ground surface temperature for the year, the time difference between the beginning of the calendar year and the occurrence of the minimum surface temperature, and the thermal diffusivity of the soil. These values may be found in a variety of sources including the ASHRAE Handbooks (refer to soil temperature).

Kasuda found that the temperature of the undisturbed ground is a function of the time of year and the depth below the surface and could be described by the following correlation:

$$T = T_{mean} - T_{amp} * \exp\left[-depth * \left(\frac{\pi\alpha}{365}\right)^{0.5}\right] * \cos\left\{\frac{2\pi}{365} * \left[t_{now} - t_{shift} - \frac{depth}{2} * \left(\frac{365\alpha}{\pi}\right)^{0.5}\right]\right\}$$

Where:

T [°C]	Temperature
Tmean [°C]	Mean surface temperature (average air temperature)
Tamp [°C]	Amplitude of surface temperature
Depth [m]	Depth below surface
α [m^2/hr]	Thermal diffusivity of the ground (soil)
tnow [1..365]	Current day of the year
tshift [1..365]	Day of the year corresponding to the minimum surface temperature

Water source heat pump

This component models a single-stage liquid source heat pump with an optional desuperheater for hot water heating. The heat pump conditions a moist air stream by rejecting energy to (cooling mode) or absorbing energy from (heating mode) a liquid stream. This heat pump model was intended for a residential ground source heat pump application, but may be used in any liquid source application. The heat pump has a desuperheater attached to a secondary fluid stream. In cooling mode, the desuperheater relieves the liquid stream of some of the burden of rejecting energy. However, in heating mode, the desuperheater requires the liquid stream to absorb more energy than is just required for space heating.

This model is based on user-supplied data files containing catalog data for the capacity (both total and sensible in cooling mode), and power, based on the entering water temperature to the heat pump, the entering water flow rate and the air flow rate. Other curve fits are used to modify the capacities and power based on/off design indoor air temperatures. This model takes either air relative humidity or absolute humidity ratio as an input. A scheme of the model is shown in Figure 3.

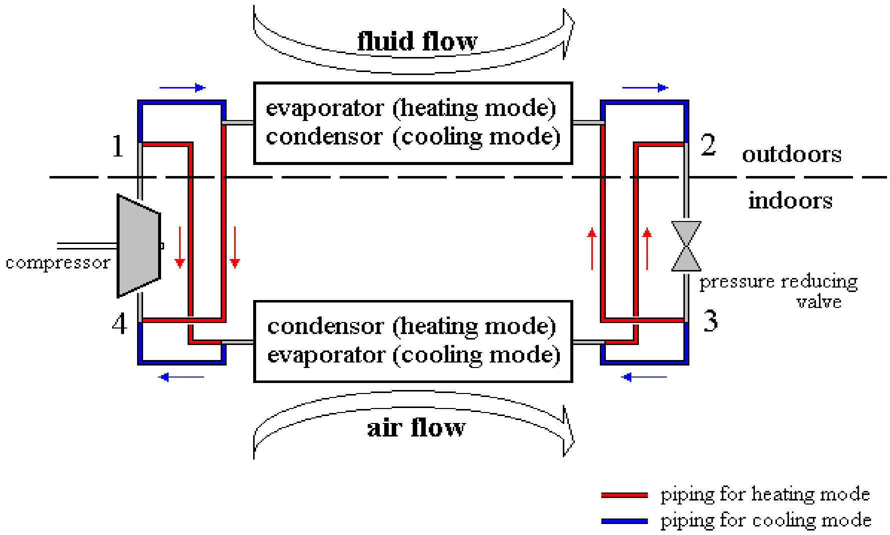

Figure 3. Heat pomp scheme in TRNSYS.

Detailed buried pipe

The pipe component models a horizontal ground coupled heat exchanger or, more simply, a horizontal pipe buried in the earth. This model accounts for ground seasonal temperature variations and backfilling of the trench containing the pipe. The fluid convection, the pipe wall, and the backfilled material are all represented as a net resistance. The inner soil nodes, those in contact with the backfill are also modeled without capacitance.

The rest of the nodes within the soil are modeled as capacitors connected by resistors in both the radial and circumferential directions.

Vertical ground heat exchangers

This is a model for a vertical heat exchanger that interacts thermally with the ground. This ground heat exchanger model is most commonly used in ground source heat pump applications. This subroutine models either a U-tube ground heat exchanger or a concentric tube ground heat exchanger. A heat carrier fluid is circulated through the ground heat exchanger and either rejects heat to, or absorbs heat from the ground depending on the temperatures of the heat carrier fluid and the ground. In typical U-tube ground heat exchanger applications, a vertical borehole is drilled into the ground. A U-tube heat exchanger is then pushed into the borehole. The top of the ground heat exchanger is typically several feet below the surface of the ground. Finally, the borehole is filled with a fill material; either virgin soil or a grout of some type. In typical concentric tube heat exchanger application, the borehole is just slightly larger than the outer pipe of the ground heat exchanger, but the same process applies. The borehole is drilled into the ground, and the heat exchanger is pushed into the borehole.

Figure 4 shows one U-tube per borehole; although this subroutine allows the user to have up to 10 U-tubes per borehole.

The program assumes that the boreholes are placed uniformly within a cylindrical storage volume of ground. There is convective heat transfer within the pipes, and conductive heat transfer to the storage volume. The temperature in the ground is calculated from three parts; a global temperature, a local solution, and a steady-flux solution. The global and local problems are solved with the use of an explicit finite difference method. The steady flux solution is obtained analytically. The temperature is then calculated using superposition methods.

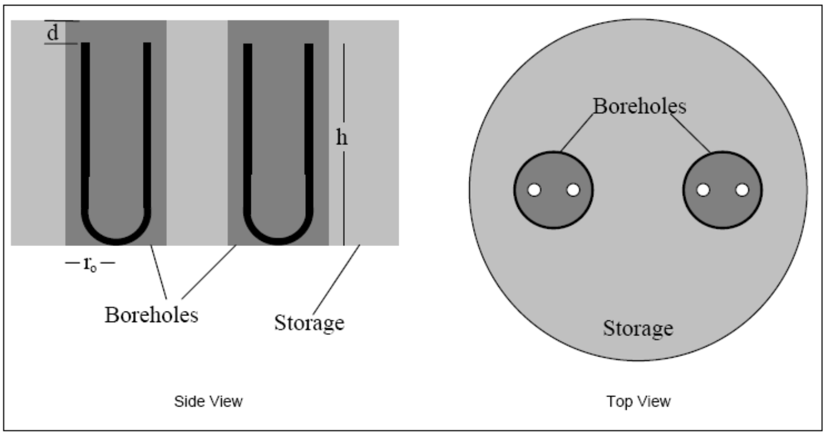

Figure 4. Side view and top view of a U-tube.

Results

The purpose of the simulation is to check the temperatures inside the greenhouse related to external climatic parameters and the type of construction of the greenhouse itself. The required energy for optimal climate conditioning is based on such calculation. These values in fact are calculated in order to maintain an optimal temperature of 20 °C which is considered suitable for the cultivation of a wide range of plant species.

The graph in Figure 5 shows the trend of annual temperatures inside and outside the greenhouse. As it can be saw, the internal temperature, represented by the red line, remains in the required range (15-24 °C) and the outside temperature, represented by the blue line, is lower in winter months (marginal parts of the graph) and higher in warmer months (middle graph). This means that geothermal air conditioning is well dimensioned, so it can provide the energy demand in the greenhouse, ensuring the ideal thermal regime for the nurse.

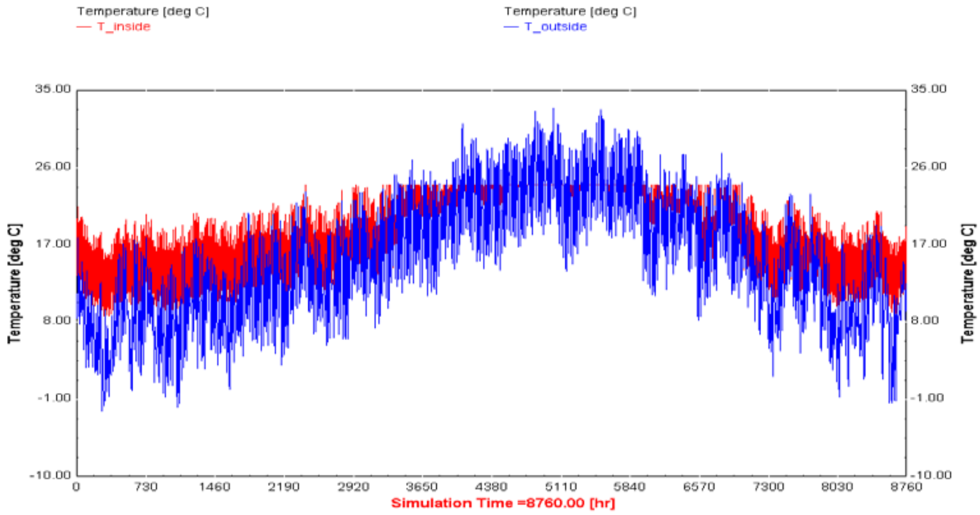

Figure 5. Inside and outside temperature annual simulation results.

After observing the evolution of temperature, it is interesting to see the 'efficiency' of the conditioning system by evaluating the efficiency of geothermal heat pump. The yield of a heat pump is measured by the Coefficient Of Performance, C.O.P., defined as the ratio between energy output (at the source of interest) and energy consumed (usually electricity). A value of the CO.P., for example 3, indicates that for every kWh of electricity consumed, the heat pump will make 3 kWh of heat. The graph in Figure 6 shows the annual pattern of C.O.P. heat pump chosen for this project, represented by the red line. As you can see the value of C.O.P. stays between 5.3 and 5.7. during the year. This can be considered an excellent result and well above common values, probably due to the simplicity of the system.

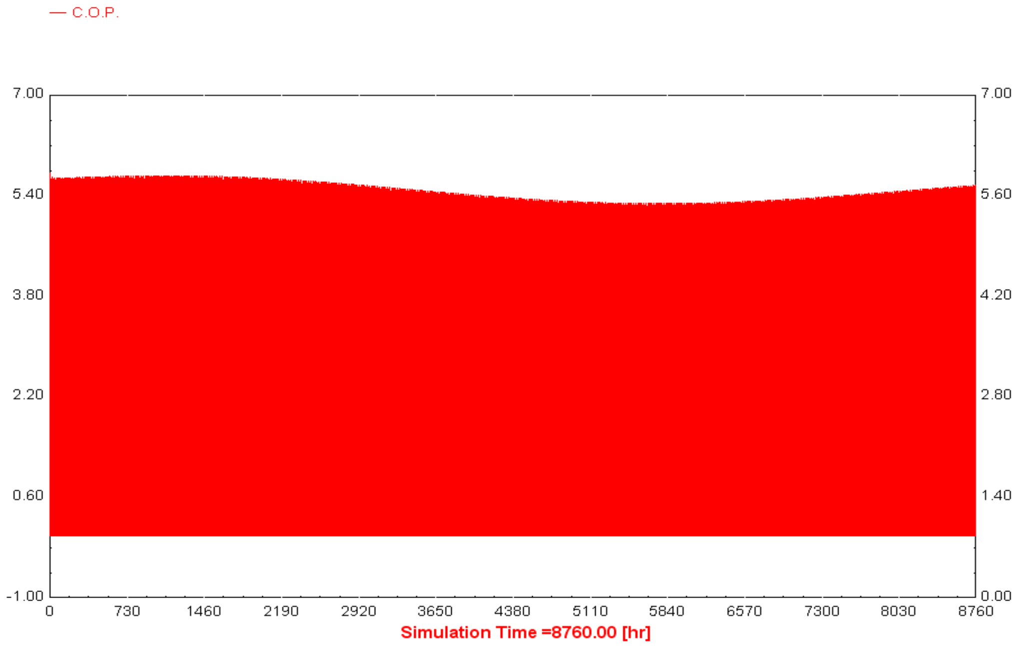

Figure 6. Coefficient Of Performance (C.O.P.) annual simulation

Once defined this optimal situation we could have results of every time-dependent variable choice from TRNSYS. For example we can know how much heat we have to put in or remove from the system for having those inside temperatures during the year, or how many electric energy we must give to the heat pump.

Conclusions

TRNSYS software has demonstrated an extreme flexibility to allow development of the project emissions. The construction of the model has been simplified by the procedures explained in a comprehensive manner in the various manuals provided with the software, without showing any particular difficulties in communications between the constituent subprograms.

From this model, it might be interesting to continue to work on projects for energy systems applied to agriculture, being able to predict the indoor climatic conditions and from this starting to figure out which crops are actually achievable.

In addition, this program offers many opportunities of improvement: could be inserted everything else necessary to simulate the best situations in the various case studies, building easily new components (Types) on variables purely "agricultural", as the plant transpiration and soil evaporation, soil temperature and soil heat exchange, crops growth and any other time-dependent variable.

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