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# Simulation and optimization of energy consumption in cold chambers from the horticultural industry


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## Abstract

Cold has been an efficient and commonly used technique in the horticultural industry as a way to preserve fruits and vegetables for more time, since the harvest until the final consumption. However, production of cold in chambers is usually done by the method of compression refrigeration cycle, which requires a large amount of electric energy.

In spite of being applied a lot of efforts in the development of new and more efficient cold production technologies (like the Peltier effect, magnetic effect or adsorption), many of them are still in a premature state and need a considerable initial investment. The great bet until the moment has been the definition and implementation of appropriated energy efficiency measures in cold chambers (as the adjustment of internal temperature, frequency of internal accesses by employees or substitution of incandescent illumination), but in practice there are a lot of companies which do not adopt them because they are of hard implementation, negligence or even lack of information..

To help companies in order to select the right measures and to evaluate their savings, it was developed a tool to simulate and optimize energy consumptions of cold chambers.


## Objectives

Present work aims to build a mathematic modeling tool that, by using a set of real input data obtained from cold chambers (temperatures, relative humidities, dimensions, products, ...), intends to estimate as an output the final electric consumptions.

It is also an intention for this tool to evaluate the potential energy savings by the adjustment and optimization of input data, helping to understand which are the most efficient measures to apply for each case.

## Introduction

From the several techniques known to preserve fruits and vegetables, cold is still one of the most efficient and widely used for several reasons: it doesn't change texture and flavor of foods, it reduces the metabolic activity of microorganisms and also prevents oxidation of nutrients. Usually, products are refrigerated at temperatures between 1 and 4 ºC (conservation for some days) or even frozen between -35 and -18 ºC (conservation for several months).

Production of cold in chambers is commonly done by the use of a process based on a compression cycle of some refrigerant fluid that, as it is passing through several states of compression / expansion, carries with him heat from the inner to the outer of chamber. This process requires a high electric energy consumption by the compressor, a fact that creates a series of disadvantages: increase of costs in electric energy bill, lost of competitive edge between companies from horticultural industry, and even the growth of greenhouse gases which difficult compromises that Portugal assumed in Kyoto's Protocol [1].

Meanwhile, new technologies to produce cold have been created as a way to overcome all inconvenients referred in the previous paragraph (like the thermoacoustic effect, magnetic effect or the Peltier's effect [2]), but because of their premature state of development and the great costs associated efforts have been conducted in order to define and implement several energy efficiency measures in the existing chambers. Simple measures like the optimum adjustment of internal temperature, the substitution of incandescent lamps by others of fluorescent or LED technology, the reduction of number of accesses to the chamber or the maintenance of thermal insulation contained inside walls, floor and ceiling help companies to achieve better energy consumptions (on 2012, it was estimated that 10,6 % of the total electric energy used in the agroindustrial branch would be saved if proper energy efficiency measures were applied [3]). Although some difficulties arise when implementing such measures because of many factors (lack of information, complexity of production process, negligence or discrediting in final results), the horticultural industry is still one of the agents that promotes highly the national economy [4], and so the study and investment in energy efficiency is fully justified as a way to improve and to promote competitive edge between companies.

It's in this context that it was developed a tool which aims to simulate and to optimize energy consumption in cold chambers, based on the adjustment of several input parameters (temperatures, relative humidities, number of accesses in the chamber, ...). This adjustment may be seen as a set of efficiency measures to apply. From the same tool is also possible to extract an idea about the energy saving that may be achieved.

## Experimental

Consumption of electric energy is determined by the amount of heat that gets into the chamber and which needs to be removed. Accordingly with [5], the mathematical model that was conceived calculates all thermal loads specified bellow and which must be removed, using appropriated mathematical expressions:

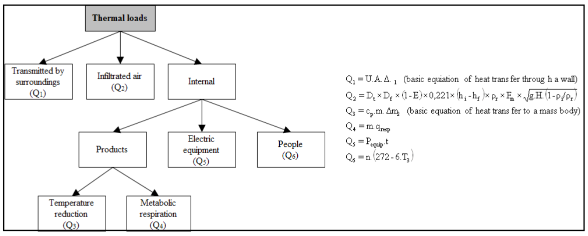


Figure. 1 - Types of thermal loads to be removed from cold chambers and corresponding equations

To determine each thermal load, all necessary input data are collected from the cold chamber to be examined and inserted into the model .

The sum of all calculated loads divided by COP (Coefficient of Performance) from the compressor provides the electric energy consumed.

2 simulations were conducted to determine the energy consumption of a garlic chamber placed in a horticultural company; relevant input data gathered from that chamber and which were inserted into the model are summarized in table 1.

| Simulation | Product accommodated | Mass of product (kg) | Chamber dimensions (m) | Insulation type | Duration of simulation (h) | Inner temperature (ºC) | Average external temperature (ºC) | Total time for opening door (min) |
|---|---|---|---|---|---|---|---|---|
| A | Alho | 8000 | 8,98×5,09×4,33 | EPS (10 cm) | 13,75 | -3 | 21,75 | 24,57 |
| B | | | | | 3 | -4 | 24,33 | 3 |

Table 1 - Relevant input data about the examined chamber and which were inserted into the model

A sensitive analysis to the energy consumption foreseen by the model was also carried out by an appropriate change of 3 input parameters (inner temperature, door opening time and installation / no installation of an air curtain above the entrance), in order to determine which are the parameters with the greatest influence in the final result.

At the end, it was accomplished an optimization of 2 input parameters (change of the set point of inner temperature to -2 ºC and installation of an air curtain) as a way to integrate energy efficiency measures and also to evaluate potential savings that may be obtained.

## Results

The following tables and charts show all predicted results determined by the model, using the methodology previously described.

| Simulation | Real active energy consumption (kW.h) | Predicted active energy consumption (kW.h) | Relative deviation (%) |
|---|---|---|---|
| A | 34,92 | 21,68 | -37,9 |
| B | 6,55 | 4,03 | -38,0 |

Table 2 - Results achieved for both real and predicted energy consumptions, in each conducted simulation.

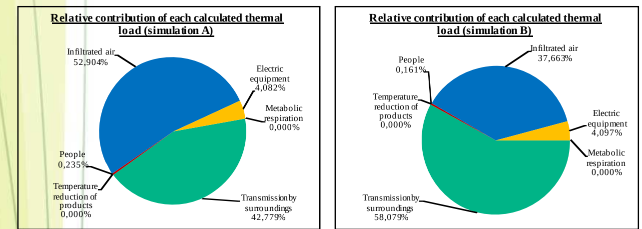


Figure 2 - Relative contribution of each predicted thermal load on the final consumption, for simulation A and B.

| Simulation | Predicted energy consumption, not optimized (kW.h) | Predicted energy consumption, optimized (kW.h) | Relative savings (%) |
|---|---|---|---|
| A | 21,68 | 12,86 | -40,7 |
| B | 4,03 | 2,77 | -31,3 |

Table. 3 - Comparison between predicted energy consumptions with and without optimization of input parameters (set point adjustment of inner temperature to -2 ºC and installation of an air curtain device above the entrance, activated when the door is opened).

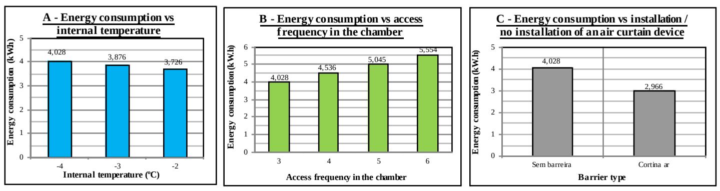


Figure 4 - Sensitive analysis of the energy consumption predicted by the model making a variation of (A) inner temperature, (B) access frequency to the chamber (considering a duration of 1 min per access) and (C) installation / no installation of an air curtain device over the entrance.

## Conclusions

The presented results show that thermal loads associated with the transmission of heat by the surroundings and infiltrated air make a strong contribution to the total energy consumption by the chamber. In both simulations, the sum of these 2 thermal loads represent about 95 % of the electric energy consumed, which means that the attention must be concentrated in the definition and integration of appropriated efficiency measures to reduce those loads.

Considerable deviations between the real and predicted consumptions were found, and this fact can be justified by the lack of exact information about composition of walls, floor and ceiling, which is hard to define with rigor.

Even so, the model allows to conclude that, through the sensitive analysis that was accomplished, the number of accesses in the chamber is the input parameter that most influences the final consumption (an increase of about 0,5 kW.h per access of 1 min of duration). Variation of internal temperature and the installation of an air curtain device are also parameters of an appreciable influence, and it can also be seen in table 3 where an optimization of both were carried out. This last optimization indicates that it is possible to get energy gains in the order of 30 - 40 %.

Although the model is still in a premature state of development, results show that it may have a great potential when used as an auxiliary tool to select the right energy efficiency measures as it is being evolving.


**References**

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