Centro Interuniversitario di Ricerca
sull'Inquinamento e sull'Ambiente - "Mauro Felli"

UNIVERSITÀ DEGLI STUDI
DI PERUGIA

PERUGIA
12|04|19

XIX

Congresso Nazionale CIRIAF

ENERGIA E SVILUPPO SOSTENIBILE

ATTI

Lectio Magistralis
SHUJI NAKAMURA
Premio Nobel per la fisica nel 2014

**Università
degli Studi di Perugia**

AULA MAGNA
Piazza Università, 1 - Perugia

Con il patrocinio di

Con il contributo di

CIRIAF - Centro Interuniversitario di Ricerca sull'Inquinamento e sull'Ambiente - "Mauro Felli"
Università degli Studi di Perugia
XIX CONGRESSO NAZIONALE CIRIAF - Energia e Sviluppo Sostenibile - Atti
Perugia, 12 aprile 2019, Università degli Studi di Perugia, Aula Magna

Perugia: Morlacchi Editore University Press, 2019.
ISBN 978-88-9392-113-8 (online)

Impaginazione e progetto grafico di copertina:
Roberto Fiorella (CIRIAF - Università degli Studi di Perugia)

Pubblicato da Morlacchi Editore University Press, Piazza Morlacchi 7/9, 06123 Perugia
www.morlacchilibri.com

A numerical model for the design of a climatic chamber for simulating moderate temperature and high humidity

Paolo Valdiserri [1,*], Eugenia Rossi di Schio [1], Valda Rondelli [2] and Enrico Capacci[2]

[1] Alma Mater Studiorum – Università di Bologna, Department of Industrial Engineering DIN, Viale Risorgimento 2, I-40136 Bologna, Italy

[2] Alma Mater Studiorum – Università di Bologna, Department of Agricultural and Food Sciences, Viale Fanin 50, I-40127 Bologna, Italy

* Author to whom correspondence should be addressed. E-Mail: paolo.valdiserri@unibo.it

---

Abstract: In the present paper, we develop a numerical analysis supporting the design of a climatic chamber suitable for tracked and wheeled tractors, i.e. having measures 5 m x 8 m x 4 m (length x width x height). Reference is made to standard summer conditions (32°C dry bulb and 25°C wet bulb), i.e. the tractor dissipates thermal power in a climatic chamber that reproduce summer temperature and humidity conditions. The numerical analysis is performed by employing Matlab-Simulink, to simulate the behavior of transient systems. First, the balance equations are written with reference to the 5 blocks that can describe the climatic chamber. Then two different regimes are investigated. First, the period is considered in order to reach the prescribed conditions for the climatic test chamber. Then, after this preparation period, the tractor's engine is supposed to work and the tractor's conditioning system is tested in order to maintain safe working conditions in the cabin

Keywords: Climatic chamber; numerical analysis; transient analysis; Matlab Simulink; dynamic programming

---

1. Introduction

Very often the design of a climatic chamber is based on experience and left to the companies charged for its realization. However, especially when dimensions are big and if it is supposed to work for long lasting measures and with high heat loads to be removed, realization costs are huge and a

ISBN (online PDF) 978-88-9392-113-8 -
Published by Morlacchi Editore University Press.

detailed design is compulsory. This happens, for instance, for tractors. In fact, in order to achieve the compulsory European type approval for tracked and wheeled agricultural tractors, the European Regulation 167/2013 has to be considered and the approval test for heating, cooling and conditioning systems requires experimental measures according to the European Delegated Regulation EU 2015/208 [1-2]. In detail, the heating and cooling devices have to be experimentally tested basing the measurements on the procedure foreseen in the ISO 14269-2:1997 standard [3]. The ISO standard provides a particular heavy weather conditions, and for long periods of time.

Indeed, particular attention has to be paid to the design of chambers suitable for tracked wheeled tractors, because they display big thermal inertia. In fact, during the measure time the tractor engine has to be working and the heat load must be removed. Moreover, since the exhaust gases are immediately removed from the climatic chamber, particular attention has to be paid to the correct estimation of the heat load to the climatic chamber, especially due to convection and radiation [4-6].

Recently, the authors of the present paper presented the transient simulation for the design of a climatic chamber modeling the winter conditions [7]. In fact, for winter case the ISO standard prescribes a measure with ambient temperatures between -12 °C and the lowest ambient temperature at which the machine is designed to operate.

In the present paper, we aim to enhance the analysis presented in [7] with reference to summer season, i.e. by assuming an air temperature inside the chamber of 32°C dry bulb and 25°C wet bulb, as prescribed by the European Regulation 167/2013. We perform a dynamic numerical analysis by employing Matlab-Simulink: as is well known, in the literature, this approach has been widely introduced, also with reference to buildings [8–10].

2. Mathematical Model

In the present paper we aim to develop a numerical transient analysis supporting the design of a climatic chamber. A sketch of the system is reported in Fig. 1. The mathematical model is somehow similar to that presented in 7, but it displays some differences, in order to fit the reproduction of summer conditions.

Let us consider a climatic chamber having a surface of 5x8 m^2 and a height of 4 m. Indeed, the volume of the chamber is 160 m^3.

Let us assume that the vertical and horizontal (roof) boundaries, for a total surface of S_S=144 m^2 that bounds the climatic chamber, are insulated, made of sandwich panels of 180 mm and displaying a thermal conductivity of 0.025 W m^{-1} K^{-1}.

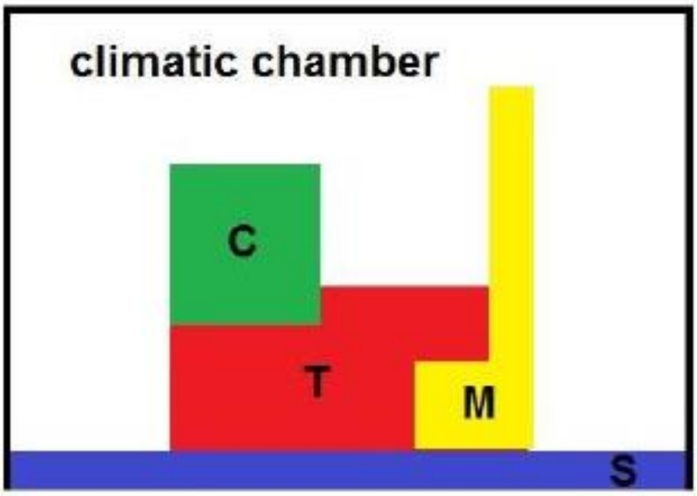
On the floor there is a screed with mass approximately M_S=12000 kg, since a thickness of 0,2 m is estimated, and the conductivity of the concrete screed is 0.8 W m^{-1} K^{-1}, the specific heat is c_S=980 J kg^{-1} K^{-1}. The screed block must satisfy the following balance equation:

$$-S_S h[T_S - T_A] = M_S c_S \frac{dT_S}{dt} \quad , \qquad (1)$$

where T is the temperature and t is the time, and the subscripts S and A stay respectively for screed and air in the climatic chamber. In eq. (1) we assume T_S as the mean temperature on the screed.

ISBN (online PDF) 978-88-9392-113-8 -
Published by Morlacchi Editore University Press.

Figure 1. Sketch of the model



In order to analyse the climatic chamber performance, inside it we model an agricultural tractor with a mass of 10000 kg and mounted with a 100 kW engine power.

As shown in Fig. 1, the track is described through three different blocks, named M, T and C. Block M, with M_M=500 kg, represents the part of the tractor that warms, due to the engine work, while block T, with M_T=9500 kg represents the part of the tractor than does not warm, because of its big thermal inertia. The tractor in the climatic chamber is required to run at the rated engine speed, with a maximum load of no more than 20 % of the maximum rated net engine power [4]. Block C represents the tractor's cabin, with M_C=5 m^3, furnished with an internal air-conditioning system (with cooling power Q_C).

The three blocks describing the tractor must satisfy the following balance equations:

$$Q_M - S_M h[T_M - T_A] = M_M c_M \frac{dT_M}{dt}, \quad (2)$$

$$-S_T h[T_T - T_A] = M_T c_T \frac{dT_T}{dt}, \quad (3)$$

$$Q_C + Q_{rad} - S_C C_C[T_C - T_A] = M_C c_A \frac{dT_C}{dt}. \quad (4)$$

In Eqs. (2) – (4), we assume that the mass M_M=500 kg and M_T=9500 kg are both made of steel, so that c_M=c_T= 550 J kg^{-1} K^{-}1. The surfaces overpassed by heat transfer are estimated in S_C=10 m^2, S_T=10 m^2, S_M=100 m^2.

ISBN (online PDF) 978-88-9392-113-8 -
Published by Morlacchi Editore University Press.

With reference to the tractor's cabin, it is full of air (c_A=1006 J kg^{-1} K^{-1}) and the windows have thermal conductance C_C=5 W m-2 K-1. Moreover, in eq. (4) the contribution of Q_{rad} = 1 kW is considered, since the heating of the climatic chamber, in order to reach and maintain the summer conditions, is done with an infrared lamp. We underline that this contribution was not considered in case of winter climatic chamber conditions, as clear in the mathematical model presented in [7].

Moreover, a mass exchanged of m_{ext}=150 kg/hour of conditioned air is assumed between the climatic chamber and the outside. A cooling system having power 400 kW extracts heat from the chamber. The direct expansion chiller group displays in the climatic chamber is the evaporator with refrigerating fluid.

According to the above description, the air in the climatic chamber can be described by a block fulfilling the balance equation:

$$\begin{aligned} &Q + S_M h[T_M - T_A] + S_T h[T_T - T_A] + S_C C_C[T_C - T_A] \\ &\quad + S_S h[T_S - T_A] + S_A U_A[T_{ext} - T_A] + \dot{m}_{ext} c_A[T_{ext} - T_A] = M_A c_A \frac{dT_A}{dt}, \end{aligned} \tag{5}$$

where $Q = Q_M + Q_C + Q_{rad}$.

In the present analysis, the power in order to keep the prescribed wet bulb temperature is not taken in account.

3. Discussion of the results

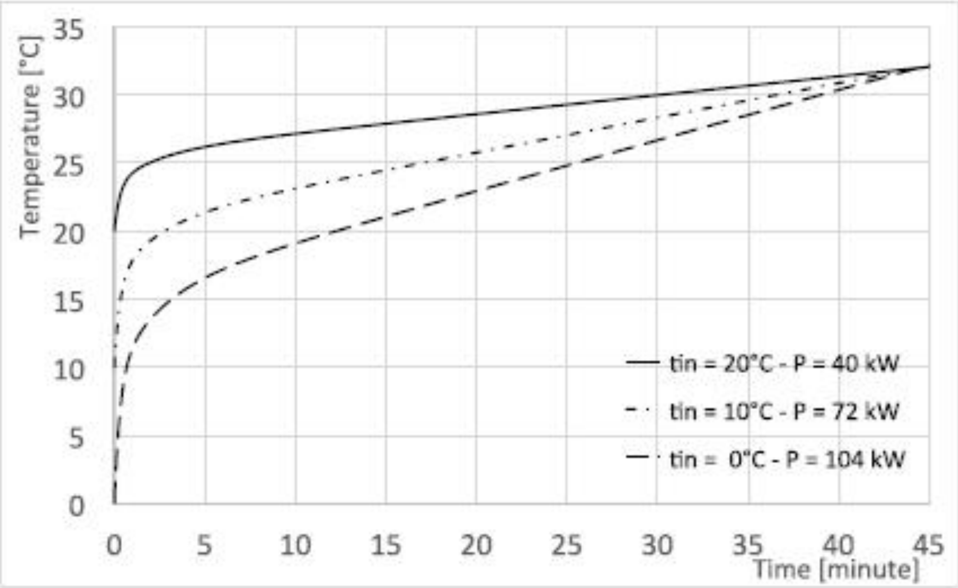
In order to simulate dynamically the behavior of the climate chamber, with particular attention to the chilling power Q and to the tractor's cabin temperature, let us assume that we refer to the following experimental measure regime.

First, we assume that the tractor is located inside the chamber ant that a previous measure in the cabin in " winter conditions" may have occurred. For this reason, the initial temperature of the air in the cabin may be low. We will investigate three cases, T_{in}=0°C, T_{in}=10°C and T_{in}=20°C and suppose to estimate to reach the prescribed conditions for the air chamber temperature, i.e. 32°C dry bulb and 25°C wet bulb, in 45 minutes time.

In order to reach this goal we switch on the heating system and we switch on the tractor's engine (if it needs), at rated engine speed without load with hourly consumption estimated in 8 kg/hour of diesel fuel. Figure 2 shows the time-dependence of the mean temperature distribution in the climatic chamber at the three initial temperature of the air and the different power (P) that it needs in the three cases in order to reach the air temperature of 32°C after 45 minutes.

ISBN (online PDF) 978-88-9392-113-8 -
Published by Morlacchi Editore University Press.

Figure 2. Mean temperature distribution in the chamber, versus time, in order to reach the prescribed conditions



After this preparation period, we check that the prescribed conditions are reached and the 60 minutes measure starts.

We increase the tractor's engine work to 300 kW.

In order to keep the air temperature at 32°C, a cooling system having maximum power 400 kW extracts heat from the chamber. The direct expansion chiller group displays in the climatic chamber is the evaporator with refrigerating fluid.

The initial temperature strongly affects the measuring conditions as well, as clearly reported in Fig. 3, where the chilling power, dynamically controlled, is reported during measuring time.

The figure displays the time-dependence of the cooling power provided by the evaporator in the climatic chamber in order to maintain the temperature of the air close to 32°C, assuming the three different values for the initial temperature (and t=0 corresponds to the exact moment when the tractor's engine is switched on to the power required by the regulation). The figure shows that the power increases as a function of time and it is higher when the starting temperature is greater.

In Fig. 4, the tractor's cabin temperature is reported with reference to the measuring period. Figure 4 shows the temperature in the cabin, versus time for three different values assumed by the cooling power QC, t=0 corresponds to the exact moment, after 1 hour, when the it starts to switch on the air conditioning system.

ISBN (online PDF) 978-88-9392-113-8 -
Published by Morlacchi Editore University Press.

Figure 3. Chilling power during measuring time, versus time

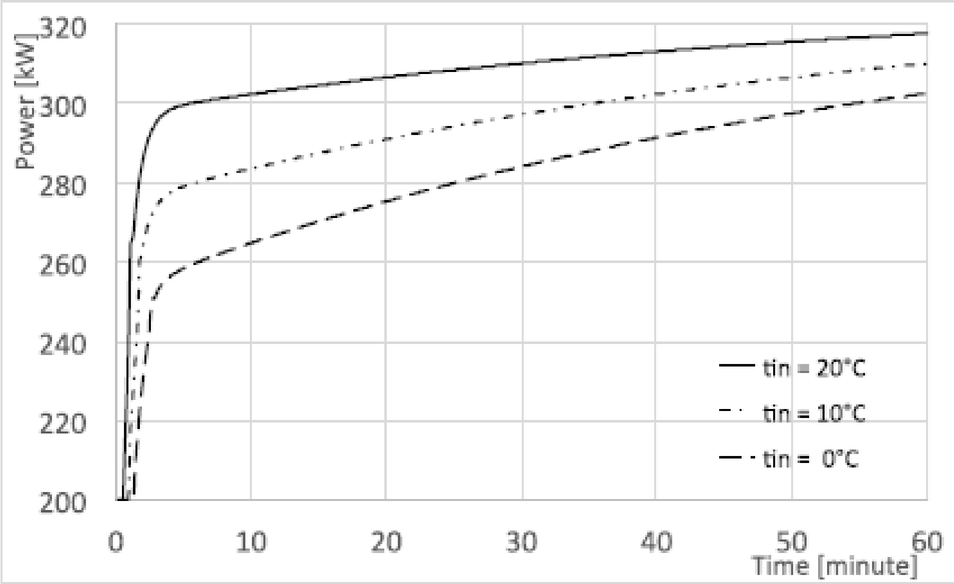
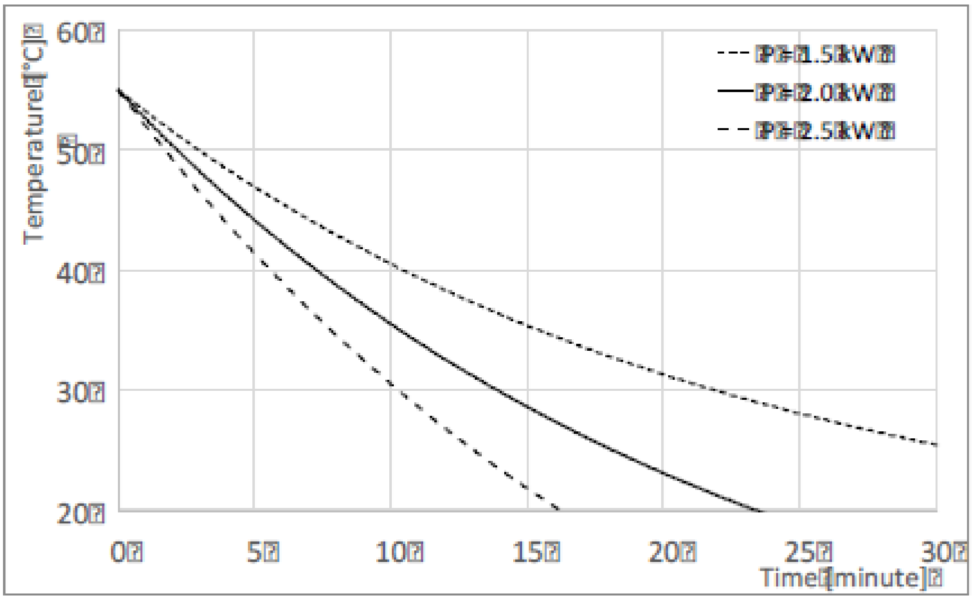


Figure 4. Temperature distribution in the tractor'cabin, during measure, versus time



ISBN (online PDF) 978-88-9392-113-8 -
Published by Morlacchi Editore University Press.

5. Conclusions

In the present paper a numerical transient simulation of the behavior of a climatic chamber is presented. Reference is made to a big chamber, suitable for the testing of tractors according to the European regulation EU 167/2013 and to the ISO 14269-2:1997 regulation.

First, the balance equations are written by considering five different blocks. Then the solution is obtained by employing the software package Matlab Simulink.

Reference is made to particularly heavy summer conditions, as prescribed by the above mentioned European regulation, and first the prescribed conditions of air temperature in the chamber are reached, then the testing time is numerically simulated.

The presented analysis shows that a transient analysis may be a useful support in order to simulate, and indeed design, a climatic chamber, particularly in the special case of huge dimensions.

However, the present paper presents a preliminary analysis of the topic. Further analyses and developments may include, for instance, the role of humididy.

References

1. European REGULATION EU 167/2013 on the approval and market surveillance of agricultural and forestry vehicles, 2013
2. European COMMISSION DELEGATED ACT (EU) 2015/208 supplementing EU Regulation 167/2013 with regard to vehicle functional safety requirements for the approval of agricultural and forestry vehicles, 2015
3. ISO 14269-2:1997 Tractors and self-propelled machines for agriculture and forestry - Operator enclosure environment - Part 2: Heating, ventilation and air-conditioning test method and performance, 1997
4. Bourhis, G., Leduc, P., Energy and Exergy Balances for Modern Diesel and Gasoline Engines, Oil & Gas Science and Technology – Rev. IFP Vol. 65, pp. 39-46, 2010
5. Okamoto, T., Uchida, N., New Concept for Overcoming the Trade-Off between Thermal Efficiency, Each Loss and Exhaust Emissions in a Heavy Duty Diesel Engine, SAE Int. J. Engines Vol. 9, 2016
6. Chintalaa, V., Kumara, S., Pandey, J.K., A technical review on waste heat recovery from compression ignition engines using organic Rankine cycle, Renewable and Sustainable Energy Reviews Vol. 81, pp. 493–509, 2018
7. Rossi di Schio, E. Valdiserri, P. Rondelli, V. Capacci, E., A numerical model for the design of a climatic chamber, 13th Conference on Sustainable Development of Energy, Water and Environment Systems Sdewes, Palermo, Italy, 2018
8. Lorenzini, M; Valdiserri, P.; Pagnoni, M., The role of the saver in a HPLCs heat transfer process: A transient analysis, JOP Conference Series Vol 796, 796, pp. 1 – 9, 2017
9. van Schijndel, A.W.M., Integrated modeling of dynamic heat, air and moisture processes in buildings and systems using SimuLink and COMSOL, Building Simulation Vol. 2, pp 143–155, 2009

ISBN (online PDF) 978-88-9392-113-8 -
Published by Morlacchi Editore University Press.

10. Mendes, N., Oliveira, G.H.C., de Araújo, H.X., Building thermal performance analysis by using Matlab/Simulink, Seventh International IBPSA Conference Rio de Janeiro, Brazil August 13-15, 2001

ISBN (online PDF) 978-88-9392-113-8 -
Published by Morlacchi Editore University Press.