Factsheet

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Renewable cooling: optimal design and control largely reduces need of mechanical cooling

The task of finding an optimal design and control sequence for a cold store may be treated as a mathematical problem. An algorithm to solve this problem has successfully been applied to a cold store in simulation, resulting in an insight into the cost effectiveness of specific refrigeration technologies. For an example cold store in The Netherlands evaporative cooling is shown to be too expensive, while ventilation in combination with mechanical refrigeration is economically viable if the cold store is to be used in January.

Most food in consumers' fridges has spent some time in a cold store. Such stores are essential to the world's food supply chains. The amount of electricity consumed by such stores is vast: in the Netherlands this amounts to 7 PJ annually at a cost of M€ 200. Consequentially one design criterion for cold stores is a minimisation of costs. This can be achieved through reducing investment costs and by saving energy during operation. Sustainable cooling technologies make such energy savings possible, but are weather dependent and often have high investments costs. Hence a combination of technologies is required, and deciding which combination and which capacity needs to be installed is a problem that must be tackled in the design stage.

In practise hardware design and controller design are two separate processes, where the control design is adapted to the apparatus that has been chosen based on static design rules. This two-step process is almost always suboptimal with respect to minimizing both investment *and* operating costs. A fully optimal solution may be achieved if both hardware design and control design are treated as a single, integrated problem.

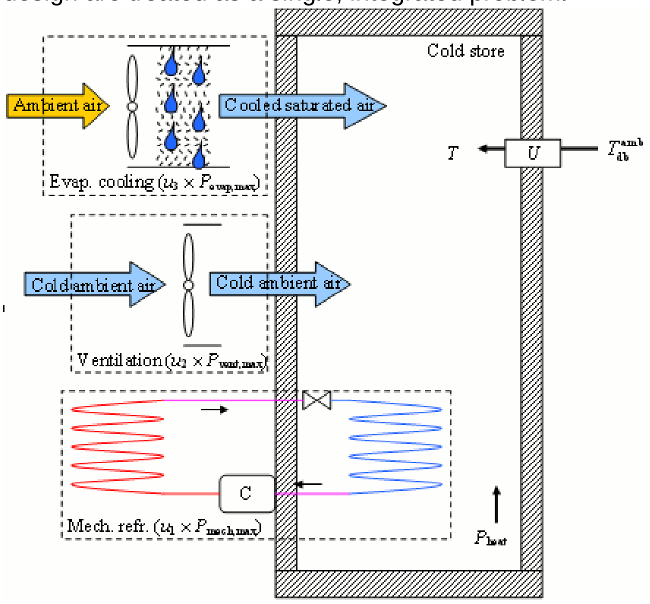

Figure 1. Schematic cold store

Methodology: OCDP

Mathematical methods for finding optimal designs and optimal control sequences may be combined in one Optimal Control and Design Problem (OCDP). This problem is solved by an iterative algorithm, which simultaneously searches for the most effective combination of design *and* control parameters using:

- a dynamical process model of the cold store;
- installation and exploitation costs and refrigeration capacity per cooling technology;
- (predicted) disturbances acting on the model;
- user-defined boundary conditions.

Example: mechanical cooling of potato storage needed?

Consider a potato cold store in the Netherlands (Fig. 1), equipped with mechanical refrigeration (u_1), ventilation (u_2) and evaporative cooling (u_3). The control aim is to keep the temperature T around 5±0.5 ºC while the ambient air conditions T_{db} (dry bulb) and T_{dp} (dewpoint) vary. The electricity tariff e is variable.

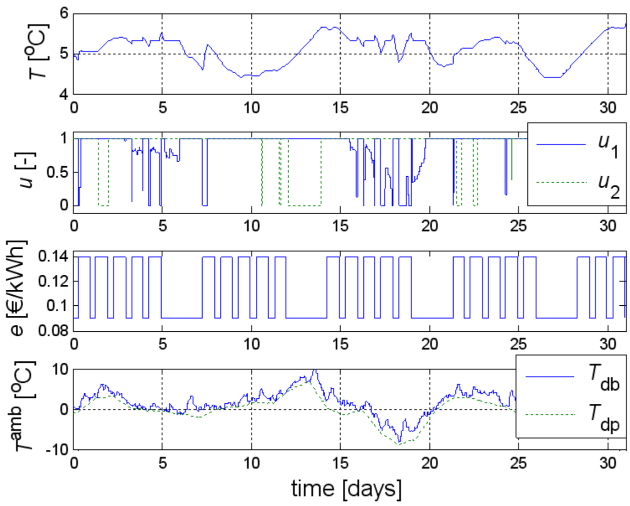

Figure 2. Optimal control solution for potato storage studied; January solution.

The OCDP is solved for January (results in Fig. 2; $u_3=0$). The optimal design consists of installing 17.5 W/m^3 mechanical refrigeration capacity and 3.2 (m^3/h)/m^3 ventilation capacity, with u_1 and u_2 their respective optimal control sequences. Furthermore, when both technologies are installed, the control sequence prefers ventilation over mechanical refrigeration to reduce operating costs. Evaporative cooling is not cost-effective in this specific situation, and is not installed.

Example: cooling control oriented at product's needs

Even with existing cooling equipment, substantial energy savings are possible. This is demonstrated by the development of the QUEST concept.
QUEST uses an innovative control of refrigeration of perishable products during container transportation. The principle of Quest is that the refrigerating system of the container works optimally based on the actual needs of the specific product.
Quest only involves changes to the software of the cooling unit and is therefore easy to implement.
Supported by years of research, experiments in the laboratory and on test journeys, much confidence in the method has been generated such that it has been implemented on a large scale.
QUEST reduces the energy need for reefer refrigeration by averagely 50%. It is being implemented world-wide.

QUEST was developed by AFSG, in co-operation with Maersk Line and Carrier Transicold, with financial support by the Dutch ministry of economic affairs (program EET) and the Dutch ministry of Agriculture, Nature and Food Safety.

Conclusions

Through optimal design and control still substantial savings of energy use for cooling can be achieved. In essence, relating knowledge at various levels is crucial for optimal systems:

- product level (what are actual demand from the product);
- knowledge about the external loads (preferably including predictions for coming period);
- system behaviour.

Above examples demonstrate saving potential.

Sources and further info

Lukasse, L.J.S., J.E. de Kramer-Cuppen and A.J. van der Voort (2007). A physical model to predict climate dynamics in ventilated bulk-storage of agricultural produce. *International Journal of Refrigeration*, **30**, pp. 195-204.

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