Inside story
Green Star and IEQ
Predictive Control of Refrigerated Facilities for Improved Energy Management – Part 2

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ABSTRACT
This article presents preliminary results from a real-world case study of predictive refrigeration control technology being developed by the CSIRO. The technology is designed to intelligently alter the operation of a refrigeration system by dynamically determining optimal operating temperature set-points and run-time schedules to reduce energy consumption and operating costs, while maintaining local constraints such as capacity control, defrost cycles, product quality and safety. Utilising “self-learning” model predictive control (MPC) techniques from control theory and computer science domains, the technology makes use of forecasting to move away from a reactionary control philosophy. By taking into account anticipated external conditions, electricity tariffs, and adaptively learning the thermal response of the system, more optimal control and pre-cooling strategies can be employed tailored to operating objectives, including minimising operating cost and reducing energy consumption, while ensuring internal temperature conditions are satisfied.

1. INTRODUCTION
A preceding Part I to this article (Wall et al., 2015) provided an overview of the CSIRO’s predictive refrigeration control technology, having successful applied similar techniques to the intelligent control of HVAC systems in commercial buildings (Ward et al., 2008). As mentioned in Part I, a recent technology report (OEH, 2011) produced by the New South Wales government Office of Environment and Heritage (OEH) outlines 15 energy-saving technologies and techniques available to increase the energy efficiency of an industrial refrigeration plant, ranging from equipment upgrades through to plant process and control optimisation and maintenance. The CSIRO predictive control technology can be considered as an automated supervisory control strategy, i.e. being concerned with the optimal control of the overall plant to achieve higher-level system objectives such as energy and cost savings (taking into account information such as weather forecast and electricity pricing information), as opposed to local-level control such as sub-system components and processes and parameters controlled by PID control loops. Referring back to the technology options as categorised in the OEH report, CSIRO’s predictive control technology can be categorised as a combination of remote control optimisation of refrigeration plant and variable cold store temperatures. The subsequent section presents preliminary results from a real-world case study undertaken to demonstrate just some of the potential of this type of supervisory control technique.

2. REAL-WORLD CASE STUDY

2.1 Cold storage facility overview
The facility used in this preliminary case study is located at the CSIRO Energy Centre in Newcastle, NSW, Australia, consisting of a walk-in freezer room with a volume of approx. 89 cubic metres and dimensions 6.5m (L) x 2.85m (W) x 4.8m (H). The facility was designed to operate at a set-point of -20°C; however, the current contents being refrigerated can easily tolerate a more energy-efficient set-point. Hence it is currently controlled at between -10°C and -15°C, depending on the product being stored.

The facility is refrigerated by a semi-hermetic reciprocating air-cooled compressor/condenser unit (Kirby model D3DA50X170) operating on refrigerant R404a. The evaporator unit (model KHDF 109) is an electric-defrost low-temperature coil. Room-temperature control is achieved via a digital thermostat controller that operates a solenoid valve fitted in the liquid line. Consequently, the condensing unit is a pump-down system.

2.2 Experimental set-up
In addition to the normal contents being stored in this facility, two 1000-litre intermediate bulk containers (IBCs) filled with reticulated water were used to introduce some additional thermal mass into the refrigerated space to more closely reflect a commercial facility.
Figure 2 and figure 3 present the results of two experiments with set-point changes to illustrate the potential for cost savings through energy-management-control scenarios. Figure 2 shows the first experiment (set-point reset strategy), where the freezer room temperature set-point is changed from -10°C to -7°C for two hours. We can observe that the power demand is reduced during this period; however, some power is still required to maintain the room temperature at the new set-point.

In Figure 3 the same set-point change is preceded by a pre-cooling period, during which the set-point is first lowered to -13°C. It is observed in this case that no power is consumed during the period at -7°C. This illustrates the potential for cost savings by avoiding peak price electricity periods.

Note, however, that this particular pre-cooling scenario ends up using more energy in total (22.26kWh) than that of the set-point reset strategy (19.08kWh), which may not always be the case. If, however, the refrigerated facility had much slower dynamics as exhibited in large cold stores and refrigerated warehouses or with more thermal mass, predictive control technology could perceivably optimise the compressor runtime to occur during more energy-efficiency ambient conditions, thus could potentially save some energy in certain circumstances.

### 2.3 Experimental results

Figure 1 shows a scatter plot of energy per cooling-on cycle versus outside temperature for different freezer temperature set-points, namely -12°C, -15°C, -18°C and -20°C respectively, captured over summer and autumn months in 2013. As the
normal operating set-point for this facility is -15°C, arbitrary set-points both above and below this value have been chosen to reflect plausible variations experienced under typical energy-management scenarios (e.g. pre-cool and demand-response) and to highlight the energy performance of such variance. Based on this data, Table 1 lists indicative energy savings for ambient temperatures of 15°C and 30°C respectively.

The results show that for this particular facility over the time range that data was collected, raising the temperature set-point (i.e. set-point reset strategy) by 3°C results in energy savings of 26% and 38% for ambient temperatures of 15°C and 30°C, respectively.

Similarly for pre-cooling-type energy-management control scenarios where temperature set-point may be temporarily lowered to store energy in the thermal capacity of the stored product, lowering the temperature set-point by 3°C resulted in increased energy consumption by 17% and 26% for ambient temperatures of 15°C and 30°C, respectively. The energy implications of this type of set-point manipulation depend on the durations of the pre-cool and set-point reset periods, in addition to a range of system variables including ambient conditions, system capacity, and the thermal mass and response of the room.

This type of indoor temperature set-point variation could be performed manually by a facility manager based on detailed knowledge and experience of the refrigeration plant over time. Yet an automated approach could facilitate the selection of more optimal set-points for achieving the greatest impact, given particular operating objects (e.g. cost or energy savings – or any combination in between), and allow a facility manager to look at “what if” scenarios before actually changing any actual system set-points or parameters.

3. CONCLUSION AND FUTURE WORK

This paper has presented preliminary results of a predictive refrigeration control technology being trialled on a small-scale facility at Newcastle, NSW, Australia. This pilot demonstration is intended to build the case for more advanced control of commercial and industrial refrigerated facilities for achieving both improved operating cost and energy performance. The technology is designed to dynamically determine optimal operating temperature set-points and run-time schedules to reduce energy consumption and operating costs, while maintaining local constraints such as product quality and safety.

Utilising a “self-learning” MPC control technique and optimisation framework, the technology takes into account anticipated external conditions, electricity tariffs, and plant power demand to adaptively learn the thermal response of the system, enabling optimal control and pre-cooling strategies to be devised and employed without human intervention and without detailed knowledge and understanding of the plant and facility under control.

Having successfully developed a predictive modelling technique using MPC that is showing accurate prediction of indoor temperature and energy consumption a number of hours into the future, the CSIRO is currently implementing the optimisation framework around this to be able demonstrate...
a complete system technology for optimising operating cost and energy performance, having previously demonstrated similar technology in the commercial building heating, ventilation and air conditioning (HVAC) domain, with savings of up to 45% (Zavala et al. 2011). Towards this, the CSIRO is seeking industry trial partners to assist in providing further proof-of-concept, with the benefit of gaining early access to the technology.

Thus, the CSIRO Energy Flagship would like to extend an invitation to cold storage facility operators interested in a collaborative project to explore this opportunity. Please contact the authors by email.

REFERENCES


About the authors

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