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Benchmarking models for the ongoing commissioning of heat recovery process in a central heating and cooling plant

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ABSTRACT

This paper presents the development of benchmarking models for the ongoing commissioning of heat recovery process in a cooling and heating plant that provides chilled water and heating water to HVAC (heating, ventilation and air conditioning) systems on a university campus. The heat recovered from the chillers in the summer was used for the heating water loop. The proposed ongoing commissioning approach and GUI (graphical user interface) are presented. The benchmarks were developed using measurements from the BAS (Building Automation System). The results indicated that the performance indices should be analyzed at both levels: the heat exchanger and the whole heat recovery system. Although the heat exchanger (HX3) effectiveness was reduced from an average value of 0.85 in 2008 to 0.60 in 2010, the effectiveness was greater than the benchmarks limits of 0.13–0.15. That reduction did not translate into a significantly lower performance of the whole heat recovery system. The BAS was able to control the system adaptation to this degradation of performance of HX3, by increasing the heating water flow rate, with an increase of electric power of pumps of only 6%. As a result, additional heat input to the system was never required. The whole heat recovery system works within the benchmarking limits.

1. Introduction

The sector of commercial and institutional buildings accounts for roughly 15% of total energy consumption in Canada [1]. Ref. [2] revealed the conclusions from Refs. [3–5] that about 30% the energy used in commercial buildings is wasted. Proper design and installation, careful maintenance as well as retrofit and fine tuning of HVAC (heating, ventilation and air conditioning) equipment can lead to significant reduction of energy usage and cost. The interest in commissioning increased with the complexity of HVAC systems, the use of new technologies, high concerns about the quality of indoor and outdoor environment, and the efficient use of natural resources. ASHRAE released in 1989 the *Commissioning Process*, a guideline for new buildings which has been updated twice, in 1996 and 2005 [6]. It describes extensively the procedure which includes (but is not restricted to) review of design documentation, functional testing performed during equipment installation as well as the production of an operation manual. This initial commissioning ideally starts from pre-design phase and is completed at building delivery. Although not yet mandatory, commissioning is required for high performance building accreditations such as LEED® Canada for new constructions [7].

The commissioning process should logically extend to the occupation phase, to support operation and maintenance when equipment degradation and changes in operating conditions occur. Haasl and Sharp [8] developed a guide for the commissioning of existing buildings. The process consists of on-site assessment and testing to find deficiencies in the operation of systems, followed by improvements and validation. The guide presents a detailed list of measurements and tests, and a master list of deficiencies and recommended improvements. The authors also mention the continuous commissioning process, which addresses the issue of persistence of the optimized building systems, by continuously monitoring the performance and comparing against benchmarks.

Liu et al. [9] defined the Continuous Commissioning^{SM} as “an ongoing process to resolve operating problems, improve comfort, optimize energy use and identify retrofits for existing commercial and institutional buildings and central plant facilities.” First a comprehensive engineering evaluation is performed, followed by the identification of the optimal operational parameters based on measured conditions, and the implementation of the new optimal schedules. They presented several continuous commissioning

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Nomenclature

COP_{RE}	compound coefficient of heat recovery [−]
PI	performance index
Q_{HW}^{HX3}	heat transfer rate measured on the heating water side (cold side) of heat exchanger HX3 [kW]
Q_{HW}^{CSB}	heating water load of buildings [kW]
Q_{CHW}^{CSB}	chilled water load of buildings [kW]
R^2	coefficient of determination
RER	recovery efficiency ratio
R_f	fouling resistance [m^2·°C/W]
RL	relative load
RMSE	root mean squared error
RR	recovery ratio
SD	standard deviation
T_{CNDs}	temperature of condenser water leaving a chiller and entering HX3 [°C]
T_{HWr}^{HX3}	temperature of return heating water to HX3 [°C]
T_{HWs}^{HX3}	temperature of supply heating water leaving HX3 [°C]
T_{HWs}^{CSB}	temperature of heating water supplied to buildings [°C]
T_{HWr}^{CSB}	temperature of heating water returning from buildings [°C]
U	overall heat transfer coefficient [W/°C·m^2]
UA	conductance-area product [W/°C]
V	volumetric water flow rate [L/s]
ε	effectiveness of heat exchanger [−]

Subscripts

CND	condenser
CH	chiller
CHW	chilled water
EV	evaporator
HW	heating water
IN	inlet
OA	outdoor air
OUT	outlet
r	return
REC	recovery
s	supply

measures for air-handling units, central chiller and heating plants, and thermal storage systems along with case studies. The commissioning process is called continuous because the system operation should be review periodically to identify any operating problems and proposed some actions for corrections.

The terms continuous commissioning, ongoing commissioning or existing buildings commissioning are now in use. Ongoing commissioning presumes that initial, retro or re-commissioning has been performed, and the goal is to maintain its benefits.

The ongoing commissioning of HVAC systems, as presented in this paper, consists in collecting continuously measured data that is relevant for the evaluation of energy performance of equipment or system. Data is analyzed, either online or offline. The derived PIs (performance indexes) are compared against the values predicted by the PI benchmark models, which is either a target value or a value representative for the normal operation of the system. Discrepancies between observed and predicted PI may indicate the degradation in performance of equipment, presence of faults, or change in operating conditions. Messages, warnings or reports are sent to the operating team when such anomalies are detected.

Heat recovery is a key element in energy efficiency strategies for new constructions and existing building retrofits, but very few commissioning directives are available for the cooling and heating plants. Refs. [10–12] gave priority to air-side components such as air handling units. Deng et al. [13] indicated that there are significant opportunities for improvements in the central chilled and hot water plants and the corresponding water networks. Annex 47 of the ECBCS [14] described the automated and semi-automated commissioning tools for existing and low energy buildings. All those tools are at the prototype level; only one tool could be used for heating and cooling plants. Standards and computer aided commissioning tools appear to be quasi-inexistent in the case of liquid-to-liquid heat recovery from the condenser water. To the best knowledge of authors there are not scientific publications about the ongoing commissioning of liquid-to-liquid heat-recovery processes in HVAC systems. This paper is a contribution to the ongoing commissioning that uses a non-invasive approach with measurements imported from BAS (Building Automation System).

The paper presents in Section 2 the relevant literature review, followed by the description of the case study central plant (Section 3) and analysis of measurements (Section 4). The analysis of performance indices is presented in Section 5, followed by the discussion of the proposed ongoing commissioning approach in Section 6.

2. Literature review

Fouling generates a gradual decrease of the heat transfer performance caused by the accumulation of deposits or dirt on the exchange surfaces. There are some cases, mostly with shell and tube exchangers, where the fouling level reaches a plateau; the inclusion of a safety margin in the heat exchange surface area at design is sufficient to mitigate the effect. Things are different with plate heat exchangers due to the smallest cross sectional area for the fluid circulation. They might even reach a critical state when the flow is severely diminished or even blocked. A complete maintenance strategy for a heat exchanger involves defining the proper cleaning schedule and method, based on mechanical, economic or energetic criteria in its specific operation context [11]. The following sections introduce two groups of performance indices that might be used for the ongoing commissioning and preventive maintenance of heat recovery system: (1) PIs of heat exchanger, and (2) PIs of heat recovery process as a whole, including for instance the condenser and pumps.

2.1. Performance indices for heat exchangers

Kuhlmann [15] presented a computational tool to support the preventive maintenance of shell-and-tube heat-exchangers used in district heating. Temperature measurements are used to identify the fouling resistance R_f and predict the moment where a pre-set fouling limit would be reached. Zubair et al. [16] used a probabilistic approach for the risk-based analysis of the effectiveness of a shell-and-tube heat exchanger in a crude oil preheat train, using a few fouling growth models. Sheikh et al. [17] presented the minimization of the cost of operation and maintenance associated with the periodic cleaning of heat exchangers in the power and process industries. Four fouling growth models were integrated in the model. A simplified closed form solution was presented to study the optimal cycle time. Cui and Wang [18] analyzed the evaporator