Preliminary Testing of a Micro CHCP System for the Canadian Climate

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Abstract

HVAC&R related building operations account for 22% of Canadian secondary energy demand [1]. Other northern countries have similar expenditures. Cogeneration is a popular method of improving efficiency, but the heat produced must be discarded in the summer. Tri-generation is an improvement on cogeneration because it uses this heat to drive a chiller. Research in implementing tri-generation in a residential setting is important to make net-zero energy homes more attainable. A LiCl-water based absorption chiller was recently installed at the Toronto and Region Conservation Authority's Archetype Sustainable House in Vaughan, Ontario. The chiller was integrated into the house's existing cogeneration system. The house has over 300 sensors capable of a sample time of 5 seconds. Experiments were undertaken to investigate the performance of the chiller when charging. This paper presents preliminary experimental and simulation results, namely observed component and system behaviour. This work is important, as it elucidates the performance possible with a cogeneration unit that is undersized with respect to the chiller.

Keywords: tri-generation, CHP, CHCP, chemical chiller

Résumé

Le fonctionnement des équipements de CVCA et R dans les immeubles représente 22 % de la demande en énergie secondaire au Canada [1]. Dans les autres pays nordiques, les dépenses sont similaires. La cogénération est une méthode largement employée pour accroître le rendement, mais la chaleur produite doit être éliminée en été. La trigénération constitue une amélioration, car elle permet d’utiliser cette chaleur pour faire fonctionner un refroidisseur. La recherche sur l’implantation de la trigénération dans un contexte résidentiel est essentielle pour rendre plus abordables les maisons à consommation énergétique nette zéro. Un refroidisseur à absorption à eau/LiCl (chlorure de lithium) a récemment été intégré au système de cogénération de la maison *Archetype Sustainable House* de l’Office de protection de la nature de Toronto et de la région à Vaughan, en Ontario. Celle-ci possède plus de 300 capteurs qui assurent un temps d’échantillonnage de 5 secondes. Des expériences ont été menées pour étudier la performance du refroidisseur lors de la charge. Le présent article détaille les résultats préliminaires expérimentaux et de simulation, à savoir ceux portant sur le composant observé et le comportement du système. Ce travail revêt de l’importance, car il établit la performance d’une unité de cogénération sous-dimensionnée par rapport au refroidisseur.

1. Introduction

The Canadian building sector (commercial and residential) is responsible for 29% of secondary energy demand, of which 22% was due to water heating, space heating and cooling. In 2010, the last year for which data is available, residential demand in Canada was 1361 petajoules (or 16% of total domestic secondary demand) [1]. Space heating and cooling and water heating constitute the majority of this consumption (1116 petajoules) [1][2]. Cogeneration (simultaneous production of heat and electricity from a single fuel source) is more efficient than independent production and microcogeneration systems are well-suited to address this segment of residential demand. Systems with various prime movers are commercially available and have been implemented successfully [3][4]. Tri-generation (generation of heat, cooling and electricity from a single fuel source) improves the system efficiency of a micro-cogeneration system by making use of the generated heat throughout the year. Since the system is used more frequently and efficiently, the payback period is shorter [5]. The objective of the present project is to investigate the possibility of developing a residential tri-generation system for northern climates, like those in southern Canada. To this end, the cogeneration system at Archetype Sustainable House B (ASH B) at the Kortright Centre in Vaughan, Ontario has been converted into a tri-generation system with a thermally driven chiller.

1.1 Archetype Sustainable Houses (ASH)

The TRCA ASH site consists of two semi-detached houses. Each house has three floors plus an unfinished basement and a garage. House B has an in-law suite above the garage. One of the houses (House A) showcases best practices and sustainable technologies currently available on the market, whereas the other house (House B) features technologies that will be available to residential consumers in the near future. The chiller was installed in House B, which already includes an evacuated tube solar collector and Domestic Hot Water tank, a Ground Source Heat Pump, an Energy Recovery Ventilator, a drain water heat exchanger, a PV system, a wind turbine and a microcogeneration system [6][7]. The monitoring and data acquisition system for the site has a total of 300 sensors [8]. A TRNSYS model of House B was developed [9] using the losses presented in Table 1.

1.2 Cogeneration Unit

The cogeneration unit used was a Whispergen PPS24-ACLG-5. Its specification and performance are summarized in Table 2. This unit was chosen because it was found to have similar thermal efficiencies as cogeneration units based on an internal combustion engine, but was far more silent [10]. Additionally, Stirling-engines have more favourable part load performance characteristics [3]. It should be noted that the maximum output this unit is capable of is 12 kW.

Table 1: House B insulation [12]

Feature	Insulation/Losses
Basement Walls	RSI 3.54 (R20)
Basement Slab	RSI 1.76 (R10)
Above-grade walls	RSI 5.64 (R32)
Windows	1.59 W/m^2K (0.28 Btu/hr-ft2-:F)

Table 2 : CHP operational characteristics [13]

Component	Description
Engine	4-cylinder double acting Stirling engine
Burner	Single nozzle swirl established recuperating
Auxiliary burner	Cylindrical premix surface burner
Generator	4-pole single phase induction motor
Duty cycle	1-24 hours continuous operation
Electrical supply	230 Vac 50 Hz (nominal grid voltage)
Electrical output	Nominal mode up to 1000W
Thermal output	Minimum 5kW, nominal mode up to 7kW, maximum 12 kW
Fuel	Natural gas, supply pressure 17-20 mbar
Central heating system	Flow rate 8-15 l/min, maximum temperature, 85^{o}C

1.3 Thermally Driven Chiller

ClimateWell AB manufactures the thermally driven chiller (also known as a thermochemical accumulator - TCA) under consideration. The unit consists of two barrels containing concentrated LiCl solution and a control and performance monitoring system [11]. Water is used as the working fluid with lithium chloride as the sorbent. Unlike traditional absorption chillers, it utilizes solute precipitation to store energy in addition to liquid-gas phase change. As a consequence, the chiller can be charged during off-peak times and cooling can be delivered without the presence of a heat source. The two barrels can either be charged or discharged simultaneously (double mode) or in a staggered manner (normal mode). For this study, only the double mode was considered, as this requires the greatest heat sink capability during the charging phase. Satisfying this heat sink requirement satisfies requirements from all other modes, as they are far lower. Table 3 summarizes the chiller's operational requirements.

Figure 1 depicts the external connections of the chiller. Figures 2 and 3 depict the energy flows of the chiller while charging and discharging, respectively. As seen in Figure 2, the unit requires a heat input of 114 kWh for full charge. It would take roughly 9 hours for the chiller to complete charging if supplied 12 kW continuously, which is a best case scenario for the current setup .

These figures also summarize the need for an efficient and effective heat sink. Most of the heat supplied to the chiller is dumped during charging, and a comparable amount must be dissipated when providing cooling. Equally as important as the total amount of energy is the peak expected rate of heat dissipation required in service under typical conditions. The efficiency of the chiller is strongly related to the efficiency of the heat rejection system. For heat rejection, cooling towers or hot water tanks are ideal for commercial/industrial or domestic installations, respectively; swimming pools are ideal when present. The rejection circuit in the present case consists of three cascaded hot water tanks and an outdoor fan coil. The piping allows the flexibility of seven possible configurations. It is anticipated that the TCA → outdoor fancoil → tank cascade → TCA configuration will perform most favourably. If implemented successfully, this heat rejection could increase system efficiency since DHW demand can be partly or fully met without using the cogeneration unit specifically for this purpose.

Table 3: TCA operational requirements [14]

Heat source circuit	Flow		25-30 l/min
	Typical power range		15-20 kW
	Operational temperature	In	85ºC-110ºC
		Out	75ºC -100ºC
	Maximum pressure		6 bar
Distribution circuit	Flow		25-30 l/min
	Operational temperature	In	10ºC-15ºC
		Out	16ºC-21ºC
Heat rejection circuit	Flow		50-60 l/min
	Typical power range		20-30 kW
	Operational temperature	In	30ºC-45ºC
		Out	<30ºC
Energy for charging (one cycle)	57 kWh per barrel		
Energy storage capacity-cooling	56 kWh (28 kWh per barrel)		
Electrical consumption	18 W		

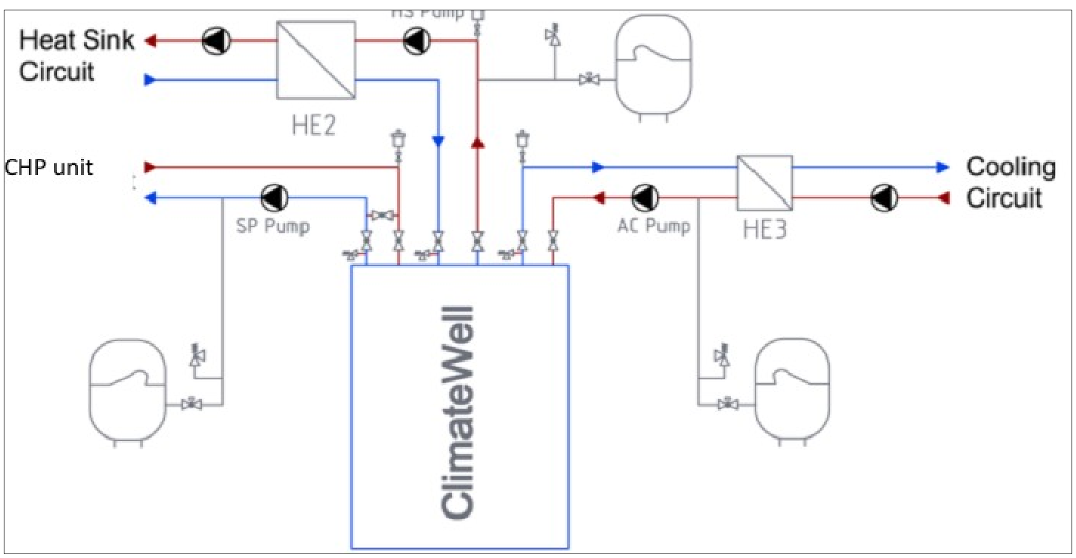

Figure 1: TCA External connections

2. Results

Two rounds of testing were performed on the cogeneration unit to test and assess electrical and thermal energy generation. In the first round, the unit was made to meet the instantaneous thermal load of ASH B. In the second round of tests, the unit was made to charge the TCA.

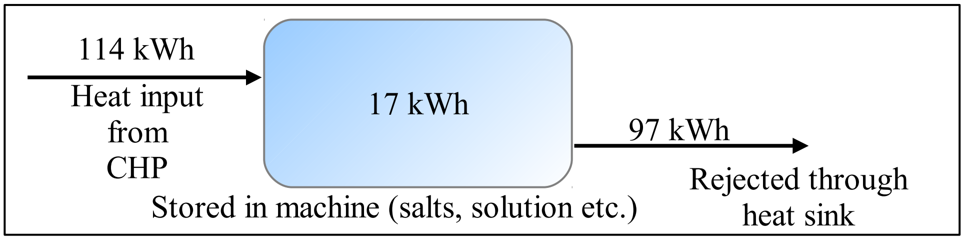

Figure 2: TCA Energy transfer when charging (Double mode) [11,14]

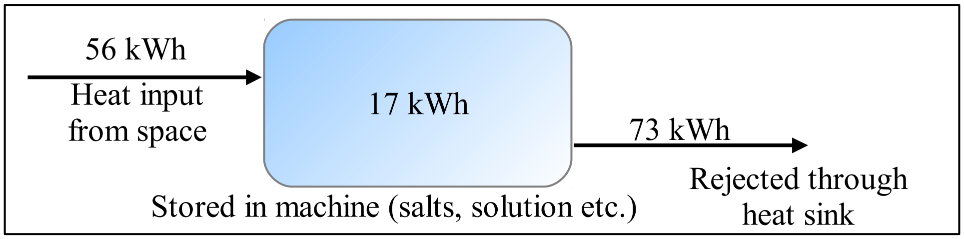

Figure 3: TCA energy transfer when discharging (Double mode) [11,14]

The main purpose of the first round was to characterize the performance of the cogeneration unit to assess the feasibility of conversion. A typical curve is shown in Figure 4. The unit was set to use only its main burner. In contrast, the performance of the unit when charging the TCA is depicted in Figure 5. Here, both burners were used and the upper setpoint was 95 °C. Integrated thermal production for this particular test was 57.3 kWh.

Figure 6 shows the heat sink circuit simulated in TRNSYS 17. The corresponding simulation results are in Figure 7.

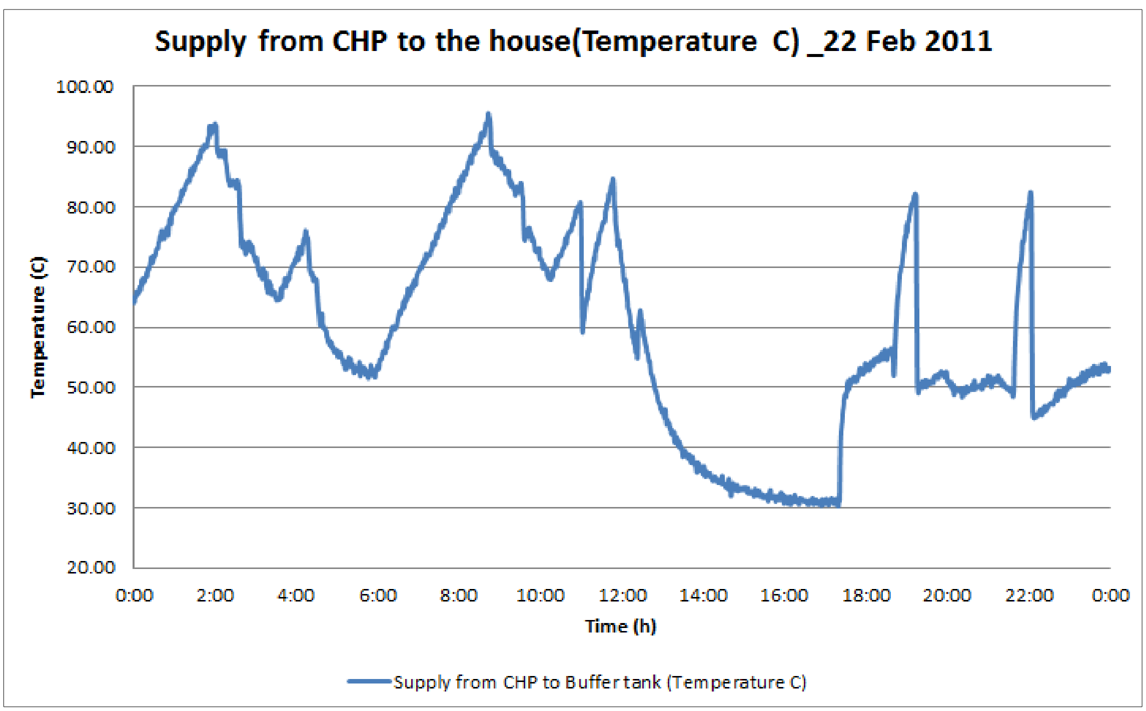

Figure 4: Cogeneration response in round one of testing

3. Discussion

The sharp peaks in the CHP supply temperature in Figure 4 (at ~4 am, ~11 am, 7 pm and 10 pm) are due to change in demand. Aside from this, the trend in case of constant demand is clear. An exponential decay function can be used to accurately model the profile between 8 am and 6 pm. Similarly, the period when the chillers are charged (Figure 4, ~5 pm – midnight and Figure 5) can be modeled using the increasing form of exponential decay. On the whole, the trend is similar to a capacitor discharging and charging, respectively.

The chiller requires high-grade heat. While the mean expected input temperature is 97.5 °C (Table 3), the maximum safe operating temperature for the CHP unit was 95 °C. Once it reached this maximum, its control logic forced it to cool down to its lower setpoint (80 ℃). The chiller was wired to signal the CHP when it required heat input. As this signal was constantly present between 4:45 PM- 4:45 AM (Figure 5), the CHP started heating immediately. This explains the relatively high frequency cycling observed in the CHP output. Increasing the flow rate of the fluid in the heat supply circuit (Figure 1) would likely solve this problem, but this was not possible during the second round of testing due to pump restrictions. In addition to increased efficiency, reducing or eliminating the cycling would also reduce the processing required for the electrical output. Thermal production was calculated to be 57.3 kWh, which is in excellent agreement with the chiller's documentation (Table 3).

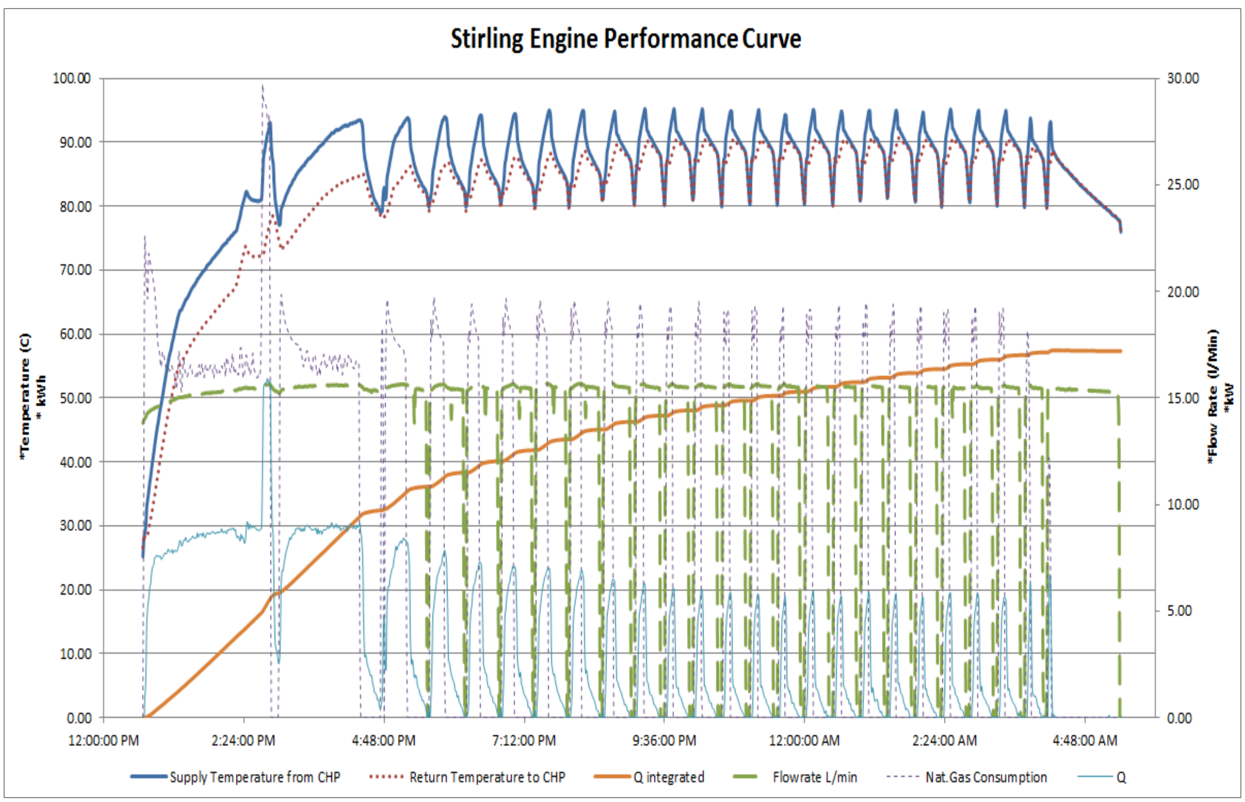

Figure 5: Cogeneration unit response in round two of testing

The heat sink simulation was performed for the hottest month in the summer in Toronto (July). It can be seen that tank temperature trend closely follow the ambient air temperature trend, as would be expected. However, there is much less variability in the tank temperatures than the ambient temperature. This is indicates that the heat sink architecture will be effective, since the temperature that the user can expect is roughly constant throughout the month. Tank 1 remained between 30 – 35 °C and tank 2 remained between 25 – 30°C for the duration of the simulation. On colder days, the fan coil is expected to reject most of the heat to the atmosphere; the tanks will predominantly store the waste heat on warmer days. In addition to the weather, the electrical demand profile of the house needs to be considered when determining an optimal charging strategy, as a greater electrical-to-thermal load ratio is associated with increased CHP efficiency [15].

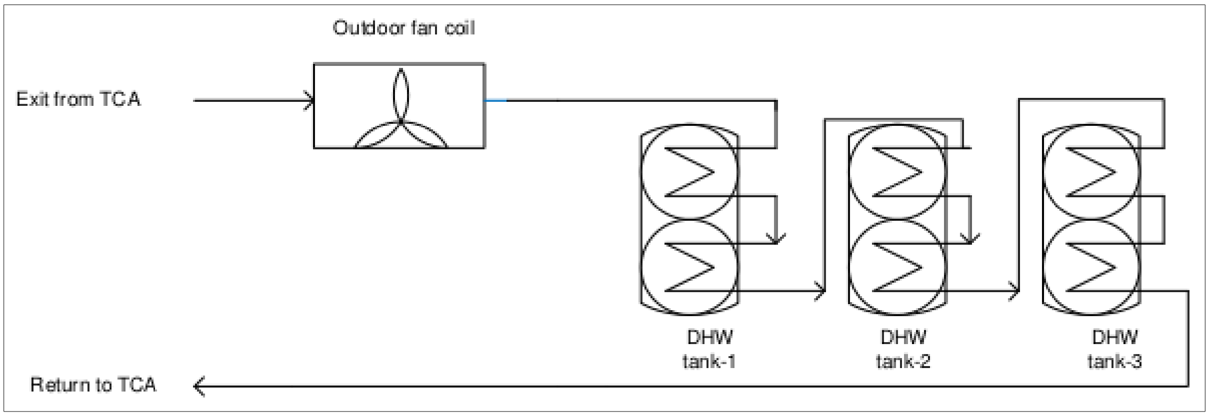

Figure 6: Simulated heat rejection circuit

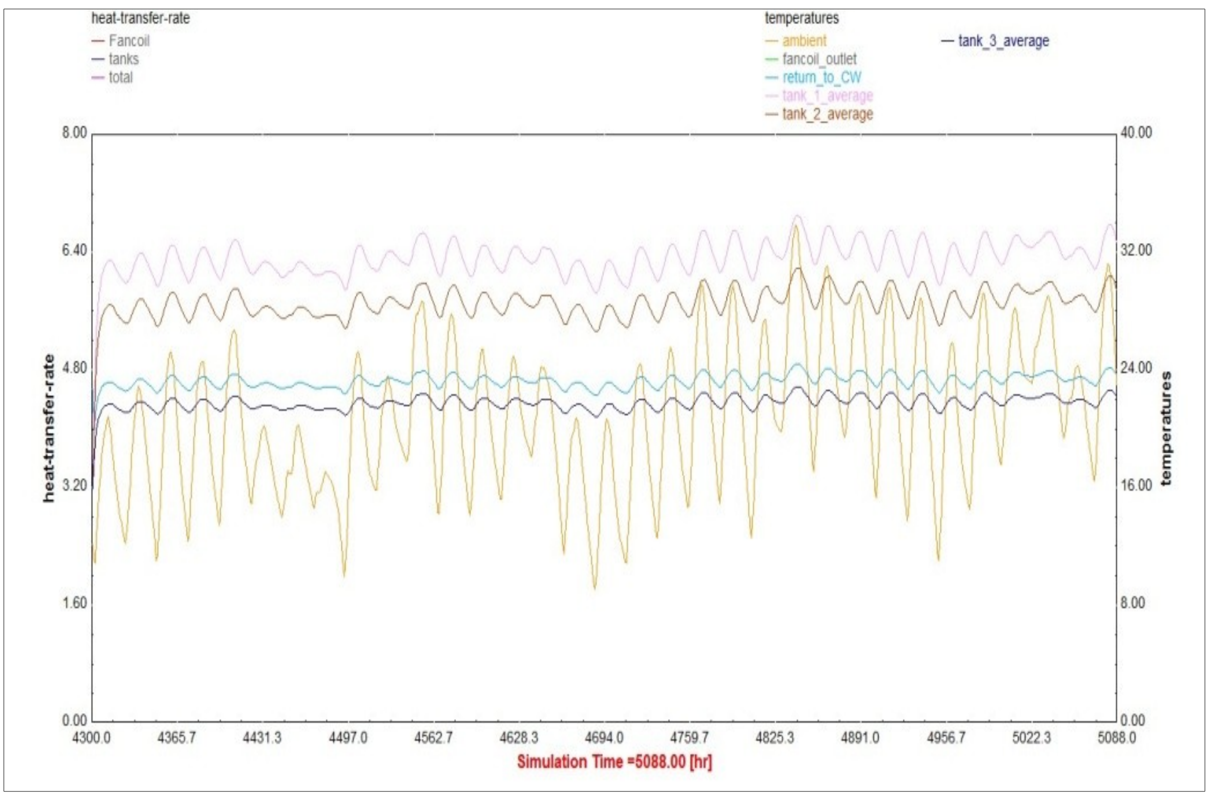

Figure 7: Simulated tank temperatures

Onoviona's simulation results [16] with an internal combustion engine-based cogeneration system indicate that controlling the unit to produce constant electrical output and storing thermal output results in greater efficiency than following electrical output. In the present case, this is not possible because there is no accumulator tank between the CHP and the chiller. Care must be taken to properly integrate a tank so that the time required to charge the tank does not add to chiller charging time. Moreover, the savings in fuel cost associated with this strategy need to be evaluated to see if they offset the cost of installing an accumulator tank. This will likely be done as a part of the next phase of the study which will attempt to use performance data to conduct an economic analysis to identify the circumstances under which conversion to such a domestic system would be viable. Barriers to adoption will also be identified and quantified.

4. Conclusion

This paper has demonstrated that the cogeneration unit in ASH B is able to charge the chiller and that the chiller is able to provide cooling. Data from the first set of tests can be used to numerically model a characteristic response from the cogeneration unit for use in simulations. High frequency cycles were observed in the temperature trace (Figure 5) when there was a persistent demand for high-grade heat. A possible remedy for this is increasing the flow rate of the fluid in the heat supply circuit.

The challenge that now remains is to fine-tune operational parameters to get optimal performance out of the system, especially for the heat sink. Ideally, the energy stored in the DHW tanks should be maximized. Work on this problem is ongoing.

Future work will also include detailed economic analysis of the conversion. This work is intended as a preliminary proof of concept. A cogeneration unit which will heat water to the chiller's recommended range will no doubt improve overall system performance, and this avenue will be explored once the proposed system has been shown to work reliably.

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7. Biography

Pushan Lele is an undergraduate student in his final year at Ryerson University (Toronto). He was the President of the ASHRAE Ryerson Branch for the 2012-2013 academic year. He interested in problems related to sustainability, and has spent previous work terms in a materials characterization lab and at a material handling solutions company. An NSERC USRA Award enabled him to work on this project, for which he is very thankful.

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Dr. Seth Dworkin joined the Department of Mechanical and Industrial Engineering at Ryerson University as an Assistant Professor in 2011. Prior to joining the faculty at Ryerson, he was a Post-doctoral fellow and Lecturer in the Department of Mechanical and Industrial Engineering at the University of Toronto. Dr. Dworkin did his graduate work at Yale University and an internship at École Polytechnique in France.

Dr. Alan Fung, P.Eng. (Ontario, Nova Scotia), an Associate Professor in the Department of Mechanical and Industrial Engineering, Ryerson University, oversees a vigorous research program on sustainable building integrated energy systems/“Net Zero” energy buildings. He participates in the NSERC Smart Net-zero Energy Buildings Research Network (SNEBRN) and works closely with public and private sectors in promoting sustainable technology development. He is also the faculty adviser of Ryerson ASHRAE Student Chapter.

Dr. David Naylor is a professor in the Department of Mechanical and Industrial Engineering at Ryerson University in Toronto. His current research interests are in the field of experimental and numerical heat transfer, with a focus on building energy systems. He has published over 150 articles in refereed journals and conferences, numerous industry technical reports, and is the co-author of a graduate level textbook on advanced convective heat transfer analysis.