GREENING HEALTH CARE
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Best Practices for Energy Efficient Boiler Plant Design, Operation and Control

A GREENING HEALTH CARE RESEARCH GUIDE

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This Best Practices Guide was prepared by Enerlife Consulting as a Greening Health Care applied research project. Greening Health Care is a program of The Living City, managed by Toronto and Region Conservation and with technical direction by Enerlife Consulting. For additional information, please contact:

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We acknowledge the support and commitment of the 15 participating hospitals listed on page 1 of the Guide, and of the project sponsors.

Toronto and Region Conservation Authority

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Table of Contents

1 BACKGROUND

This Best Practices Guide (Guide) is for use by hospital Facility Directors to help direct their engineers, service contractors, operators and controls companies in making their boiler plant performance and gas use efficiency the best they can be. The Guide is provided as a technical resource for Greening Health Care (GHC) member hospitals. Greening Health Care is a program of the Living City in operation since 2004 and managed by Toronto and Region Conservation.

Ten major acute care hospitals and five complex continuing care hospitals took part in the project, providing technical input and review as well as information on their existing systems and operations. Utility company and industry sponsors also played active roles in the project, contributing technical knowledge and funding. Findings were presented to and reviewed with member hospitals at the Greening Health Care workshop on November 29th, 2017, and during the webinar on December 13th, 2017.

Hospitals	Building Area	2016 Gas Use m3
Baycrest	988,700	1,979,878
West Park Healthcare Centre	465,403	945,668
Ontario Shores Centre	485,000	987,481
CAMH - Queen Site	662,752	1,368,765
Providence	647,605	1,347,388
Trillium Health Partners - Queensway Site	434,539	1,428,562
Michael Garron Hospital	864,930	3,101,153
Trillium Health Partners - Mississauga Site	869,068	3,130,043
Huntsville District Memorial	121,400	453,445
North York General Hospital	677,691	2,619,738
Ross Memorial Hospital	310,003	1,216,079
Credit Valley Main Hospital	771,386	3,006,975
Alberta Children’s Hospital	940,623	4,819,350
Orillia Soldiers' Memorial	385,000	1,892,895
Etobicoke General Hospital	447,175	2,211,140
Total	**9,071,275**	**30,508,560**

The GHC database shows a wide range of thermal energy performance between these hospitals, attributed in part to boiler plant performance. Boiler plants are the largest consumers of natural gas in healthcare facilities as well as the largest source of greenhouse gas emissions.

Founded in 2004, **Greening Health Care** is the largest program of its kind in North America, helping hospitals work together to lower their energy costs, raise their environmental performance and contribute to the health and well-being of their communities. Members manage data, assess their performance and track savings using a powerful online information system. They share knowledge and best practices through workshops, webinars and networking to help plan, implement and verify improvements. This is a program of The Living City, managed by Toronto and Region Conservation and with technical direction by Enerlife Consulting.

Over the past ten years, GHC member hospitals have implemented many boiler plant retrofit and replacement projects which have produced a range of gas savings results. GHC has tracked gas use before and after boiler plant replacements at Baycrest, Credit Valley and Orillia Soldiers' Memorial, summer boiler installations at West Park and CAMH and major controls upgrades at Providence and West Park. Interval metering at these hospitals allows us to directly compare the actual gas use performance of these hospitals against each other and over time.

All of this provides a rich body of data from which best design, operational and control practices can be learned, shared with and applied to all member hospitals. Getting the best practical efficiency from hospital boiler plants can lead to significant energy, utility cost and emissions savings.

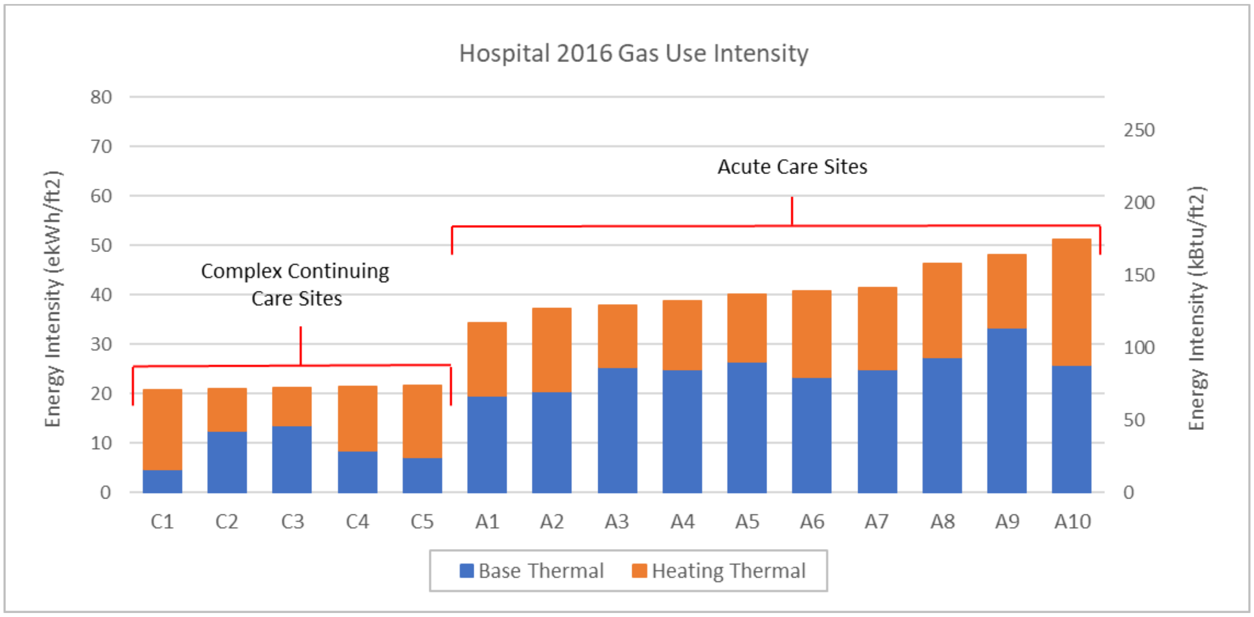
2 INTRODUCTION

This research project has created a large Database of 2016 gas consumption, hospital types and building areas for the 15 participating sites, together with information on boiler plant configurations and capacities and operational data including pressures and temperatures, water treatment and operating logs. The structure and content of the Database are presented in Appendix A. Not all boiler plant information was available for all sites, and some of it changed during the course of the project as hospitals made adjustments to improve performance. The Database will be expanded and updated over time as the current participants make improvements and complete and update their profiles, and as more hospitals join in. The Guide will be periodically updated accordingly.

Best practices were developed from the knowledge and discussions among the project participants, and reinforced where correlations between gas use intensity and boiler plant characteristics were identified. In general, such correlations were hard to find but we expect more definitive results to emerge as boiler plant upgrades and operational improvements are implemented over time and we are able to isolate the resulting gas savings. Results from this ongoing longitudinal research will be included in future editions of the Guide.

Figure 1 shows 2016 gas consumption for the 15 hospitals weather-normalized to Toronto, Ontario. Base (year-round) gas use intensity shows the biggest variation ranging from a low of 4.6 ekWh/ft2 to a high of 33.3 ekWh/ft2. Heating gas use, associated with space and ventilation heating and humidification in winter, ranges from 7.5 ekWh/ft2 to 25.4 ekWh/ft2. The other noteworthy feature of the data is the pronounced difference between Complex Continuing Care (CCC) and Acute Care sites. This difference is attributed primarily to the prevalence of ventilation reheat for space temperature and humidity control in acute care sites, which is a major area for performance improvement and gas savings in many hospitals.

Figure 1 Hospital gas use intensity in 2016



The Database is ordered from the lowest to the highest total (weather normalized) gas consumption per square foot to help identify the common characteristics of more and less gas-intensive hospitals and find correlations to support the proposed best practices. For each best practice the number of hospitals reporting they have it is provided for the Complex Continuing Care (C) and Acute Care (A) sites together with the total number of hospitals reporting on that best practice (in parentheses). Where correlations were found between a best practice and lower gas use intensity in the Database, this is indicated.

The first set of best practices (Section 3.1) is intended for use with designing new boiler plants as well as for re-configuring and retrofitting existing plants. Note that none of the participating hospitals had heat recovery chillers or combined heat and power (CHP) plants, so these are not addressed but will be considered in future editions of the Guide. The second set of best practices (Section 3.2) relates to operation and control of all central heating plants.

Every boiler plant is different, and users of the Guide are advised to consult their mechanical engineer, and their boiler and water treatment service providers, when evaluating and implementing these best practices.

3 BEST PRACTICES

3.1 Plant configuration and design

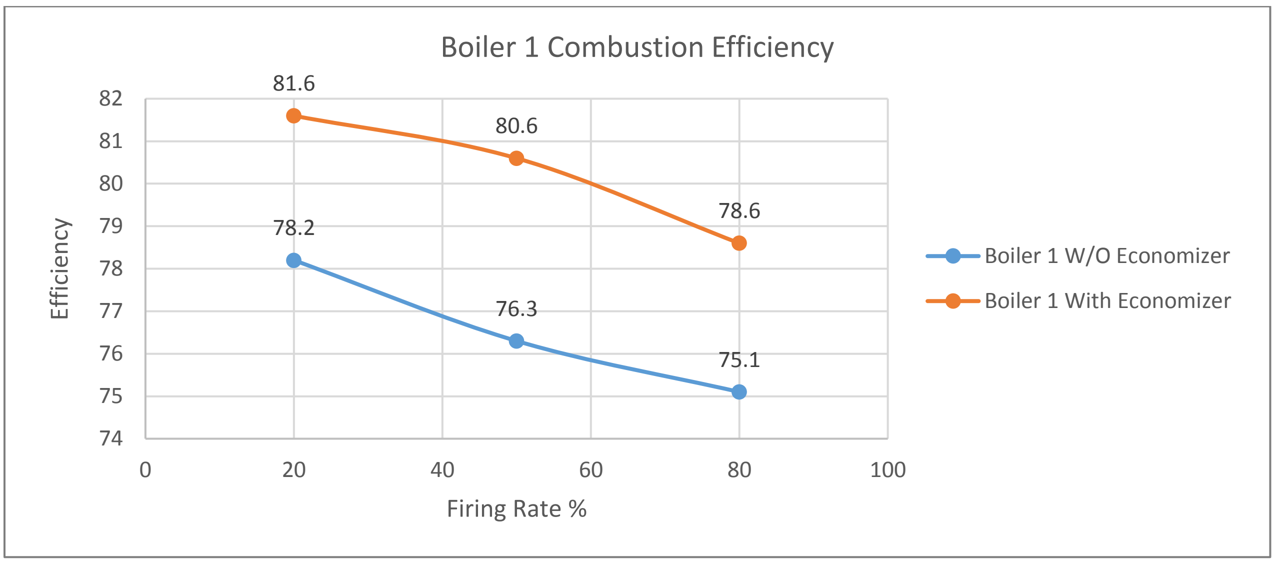
3.1.1 Boiler heat exchange surface area & flue gas economizers

Heat exchange surface area for transferring heat from combustion of fuel to produce steam or hot water is the starting point of plant efficiency. When selecting boilers, surface area per boiler horsepower (BHP) metrics should be used to evaluate options, along with the thermal output/input ratio. Some boilers come with internal or external economizers (supplementary heat exchangers) which should be included in the total heat exchange surface area evaluation.

Some heat exchangers are designed to increase turbulence and thereby improve heat transfer (which is seen in the boiler output/input ratio). These designs can increase forced draft fan motor power, and full/part-load fan power should also be included in the evaluation of options (see Section 3.1.6 VFD Forced Draft Fan).

Effective heat exchange surface area for an existing boiler can be increased by installing an external flue gas economizer to extract additional heat from hot flue gases and transfer it to boiler feedwater or hot water return. The economizer can increase efficiency by 5-10%. Figure 2 shows boiler efficiencies for one of the participating hospitals upstream and downstream of the economizer. To be effective, economizers must be clean, with good water-side flow and proper bypass control. Boiler testing can uncover problems with economizer operation (see Section 3.2.3).

Figure 2 Hospital boiler efficiencies



	CCC	Acute
# of hospitals with flue gas economizers	4 (5)	6 (6)
	# of hospitals reporting having the measure (total # of hospitals reporting on the measure)	

3.1.2 Summer boiler

Main steam and hot water boilers are sized for winter heating loads. During summer operation the capacity of these boilers is generally many times greater than the load, particularly during overnight low occupancy periods, resulting in excessive cycling on and off. Every time a boiler restarts it goes through a purge cycle which wastes energy as indicated in the table below.

Number of Cycles/Hour[1]	Percentage of Energy Loss
2	2
5	8
10	30

Excessive cycling also causes wear and tear on equipment. Radiation heat losses from the boiler shell are higher for large boilers.

Installation of a smaller, efficient summer boiler, sized for the actual summer daytime load, can significantly reduce gas consumption and extend the life of the main boiler plant.

	CCC	Acute
# of hospitals with summer boilers	3 (3)	3 (8)
	# of hospitals reporting having the measure (total # of hospitals reporting on the measure)	

3.1.3 Combination hot water and steam boiler plant

The traditional hospital practice of generating high pressure steam and then reducing pressure or converting to hot water for individual loads is inherently inefficient. Highest efficiencies result from generating heat as close as practical to the temperatures required for individual loads. Combination hot water and steam plants help achieve this objective.

For new hospital designs, a combination of properly sized high-pressure steam generation for sterilizers, separate low-pressure steam boilers for humidification, kitchen and other loads, hot water boilers for space heating and condensing boilers for domestic hot water is ideal. Each of these boilers should be located as close to its respective loads as possible and be capable of overnight and seasonal shut-down wherever possible. Where installed, heat recovery chillers can supplement space heating and domestic hot water loads.

For retrofits of existing hospitals with steam plants, addition of separate hot water boilers can improve efficiency. The bigger opportunity is in end-of-life plant replacements where right-sizing and combination plants can make a major difference to overall plant efficiency and performance.

	CCC	Acute
# of hospitals with combined hot water and steam plant	2 (4)	4 (9)
	# of hospitals reporting having the measure (total # of hospitals reporting on the measure)	

3.1.4 Linkage-less controls and O2 trim

Precise control of air-to-fuel ratio at the burner throughout the operating range maximizes efficiency. With older linkage controls the mechanical shaft between the fuel valve and forced draft (FD) fan damper controls the air-to-fuel ratio. This is usually calibrated for best efficiency at 100% (high) firing rate, and at

[1] Source: https://www.energy.gov/eere/femp/downloads/operations-and-maintenance-best-practices-guide, Chapter 9, page 14

lower firing rates, due to non-linear relationships between fuel valve and combustion damper, the air-to-fuel ratio varies making combustion less efficient.

Linkage-less controls provide precise, independent control of the fuel valve and combustion air damper (or variable frequency drive on the FD fan motor) through separate actuators. This eliminates the inaccuracy of mechanical components and allows the combustion air to be accurately set across the full range of firing rates to maintain consistent air-to-fuel ratios. Even finer control can be achieved through O2 trim which monitors the O2 level in exhaust gases and communicates excess O2 levels through a central controller to modulate the combustion air accordingly.

Typical savings from switching to linkage-less controls systems have been between 5-15% with payback of less than 2 years.

	CCC	Acute
# of hospitals with linkage-less controls	3 (3)	7 (8)
	# of hospitals reporting having the measure (total # of hospitals reporting on the measure)	

3.1.5 Modulating burner control

ON/OFF control, staged control and modulation are three methods of controlling burners. ON/OFF control is simplest and least efficient resulting in frequent cycling and corresponding inefficiency, wear and tear. Staged or step control adjusts firing rates between typically three stages - high, medium, and low. This is an improvement over ON/OFF control, but still does not match the heating load with boiler capacity causing undue cycling. Fully modulating control is the most efficient, continuously matching boiler output with variations in heating load.

Retrofitting or replacing existing ON/OFF or staged burners with new modulating controls can substantially improve efficiency without replacing boilers which may still have remaining useful life. Derating the burners where applicable can also improve efficiency and extend boiler life.

	CCC	Acute
# of hospitals with modulating burner controls	2 (3)	3 (6)
	# of hospitals reporting having the measure (total # of hospitals reporting on the measure)	

3.1.6 VFD forced draft (FD) fan

Boiler forced draft (FD) fans are typically the largest electricity consumers in the boiler plant, and some boiler designs require greater fan power than others (refer to Section 3.1.1). Standard inlet damper controls can be effective in adjusting combustion air volume as boiler loads vary but do not have much effect on FD fan electricity use. Where practical, FD fans should be specified or retrofitted with variable frequency drives (VFDs) which significantly lower electricity consumption as well as providing precise combustion air volume control.

Where practical, typical payback for this retrofit is less than 2 years.

	CCC	Acute
# of hospitals with VFD forced draft (FD) fan	2 (3)	2 (6)
	# of hospitals reporting having the measure (total # of hospitals reporting on the measure)	

3.1.7 VFD feedwater pump

Boiler feedwater pump motors are another significant electricity consumer in the boiler plant. Where feedwater pumps operate continuously, automatic control valves modulate to maintain flow rates to match steam demand. As the steam demand drops, the feedwater control valve closes but the pump motor load does not change very much. Where practical, retrofitting feedwater pump motors with VFDs can significantly lower electricity consumption while maintaining precise feedwater volume control.

	CCC	**Acute**
# of hospitals with VFD feedwater pump	0 (3)	0 (6)
	# of hospitals reporting having the measure (total # of hospitals reporting on the measure)	

3.1.8 Back-pressure valves

Back pressure valves prevent changes in pressure at the boilers (upstream of valve) as pressures fluctuate in the high-pressure steam distribution system, typically due to sudden load changes when equipment or air handling systems start up or big control valves open and close. They are installed on the main steam line(s) leaving the plant or at the outlet of individual boilers. The back-pressure valve senses the pressure drop due to the load change and closes to maintain pressure at the boilers, thereby maintaining stable operation.

Back-pressure valves should be considered for applications where sudden load changes are experienced and cannot be moderated by upgraded controls.

	CCC	**Acute**
# of hospitals with back-pressure valves	2 (3)	5 (6)
	# of hospitals reporting having the measure (total # of hospitals reporting on the measure)	

3.2 Plant operation and control

3.2.1 Reduce/reset steam pressure and primary HW temperature

Heat losses from steam and hot water distribution systems in hospitals are responsible for a significant proportion of gas consumption (seen most clearly in base thermal gas use) and are the subject of ongoing Greening Health Care research. During the cooling season, much of these losses becomes additional loads on the hospital's air conditioning systems. Reduction and dynamic reset of steam pressures and hot water temperatures can significantly lower gas consumption at low cost and with short payback periods, while improving overall building systems control.

Figure 3 shows a clear correlation between steam pressures and gas consumption for 9 of the participating hospitals. Steam pressure set-points should be maintained at the minimum levels necessary to meet the most stringent demands, typically sterilizers, in order to reduce losses due to radiation, trap leakage, flash steam, and blowdown. Depending on location of these stringent loads, required pressures may be further reset down during summer and unoccupied conditions when distribution pressure losses are less.

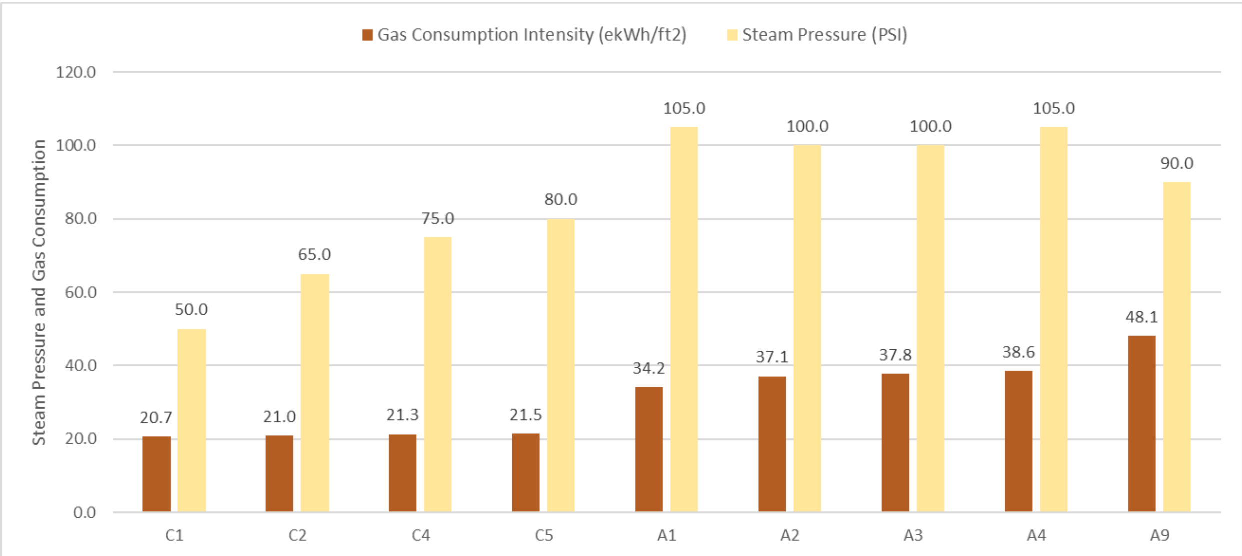
Primary hot water supply temperatures should be reduced and reset based on actual heating demand as monitored by the building automation system (BAS), and subject to manufacturer's limits.

Following are recommended considerations for minimizing distribution losses:

- lower maximum steam pressure to meet stringent load requirements on peak days
- reset steam pressure during unoccupied periods when stringent loads are not in use
- automatically reset steam pressure to maintain stringent load requirements (install local pressure sensor)
- reset primary hot water loop temperatures based on demand of individual heating systems
- shut down heating pumps when heating systems are not calling for heat, particularly during summer months

	CCC	**Acute**
# of hospitals with night reset	1 (3)	1 (6)
# of hospitals practising heating pump shutdown	4 (4)	0 (7)
	# of hospitals reporting having the measure (total # of hospitals reporting on the measure)	

Figure 3 Steam pressure and gas consumption



3.2.2 Steam line isolation

As described in Section 3.2.1 above, heat losses from steam and hot water distribution systems cause significant waste of energy, particularly during the cooling season. Shutting down steam lines to certain areas when the heating loads served are not in use can produce big energy savings. Practices for consideration are:

- Overnight shutdown to kitchen and other daytime loads
- Summer shutdown to mechanical rooms and entire buildings where the only loads are space heating and/or humidification

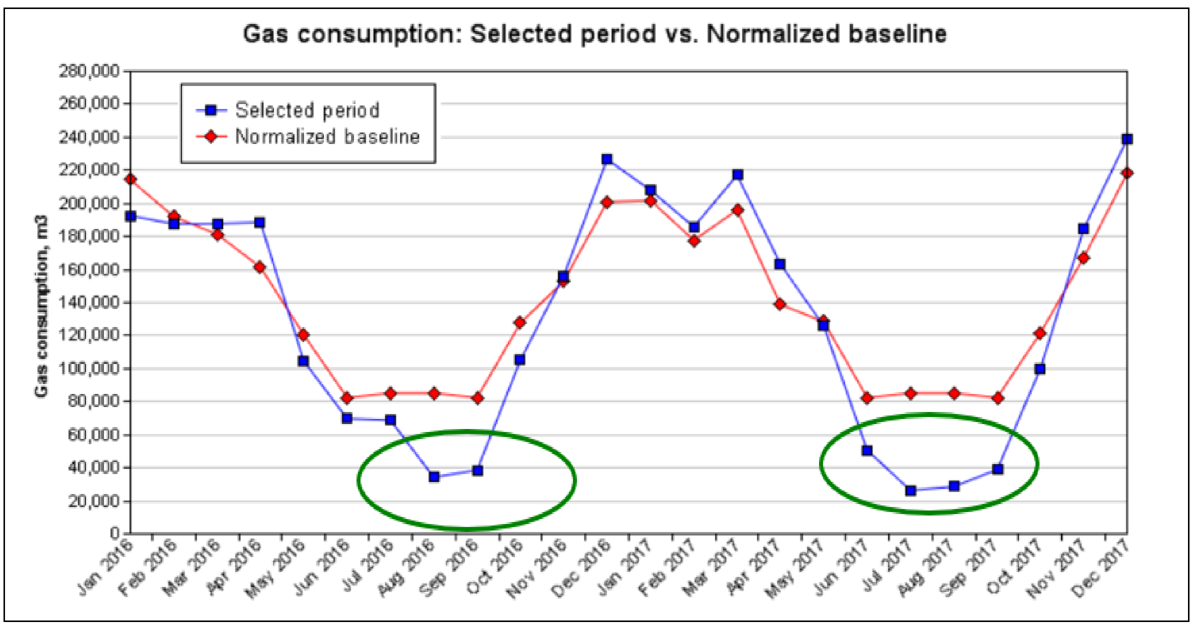
- Permanent shutdown where steam loads are no longer in operation

Implementation requires tracing the steam lines to ensure no active loads are being served, and to identify pockets where condensate build-up would cause corrosion problems. Isolation should be as close to the boiler plant as possible to maximize the length of line affected and should flush all condensate from the lines to minimize corrosion. Nitrogen blanketing should be considered to protect against corrosion. Care is needed when reactivating sections of piping to avoid shock and return of high iron content condensate to the plant.

Figure 4 shows the impact of steam line summer shutdown to mechanical rooms at Markham Stouffville Hospital, an acute care facility located just north of Toronto.

	CCC	Acute
# of hospitals that isolate steam lines in summer	0	1
# of hospitals practising overnight shutdown	1	0

Figure 4 Markham Stouffville Hospital gas savings due to summer steam line shutdown



Steam meter savings for	Aug/16-Sep/16:	56.5% - 94,673 m3, $30,326
	Jun/17-Sep/17:	56.9% - 190,626 m3, $58,366

3.2.3 Boiler testing and tuning

Boilers should be tested semi-annually for combustion efficiencies under steady, high-load conditions and tuned to achieve the best practical efficiency for each boiler. Following are recommended best practices:

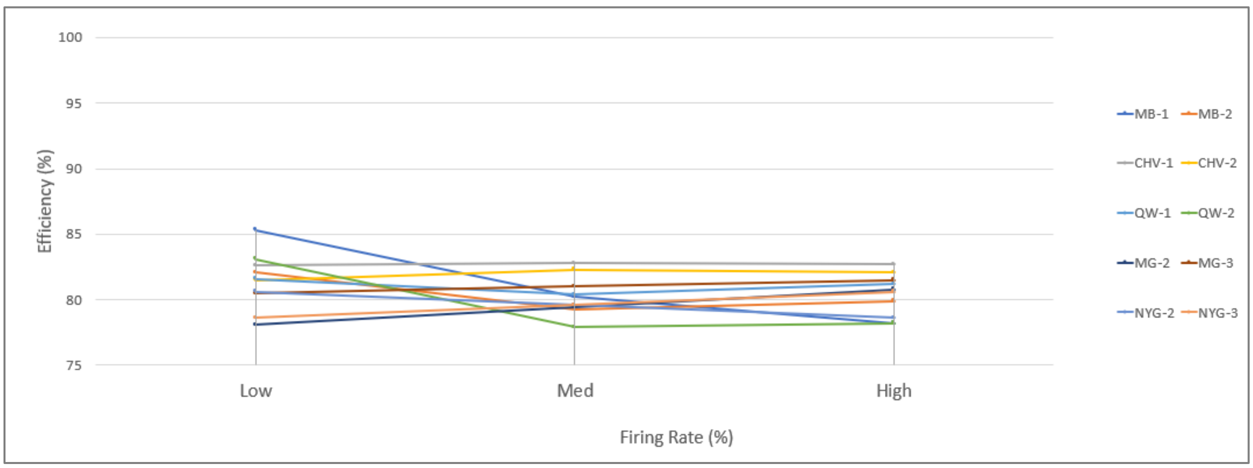
- test both upstream and downstream of external flue gas economizers (two sets of results) if installed;

- report as-found conditions as well as best performance following tuning;
- include previous test date and results and comment on changes;
- hold a formal performance review meeting with the boiler service and water treatment contractors, the plant operator, the BAS service contractor and the hospital's engineer to evaluate test results and discuss options for improvement.

	CC	Acute
# of hospitals that conduct boiler efficiency tests	4 (4)	6 (6)
	# of hospitals reporting having the measure (total # of hospitals reporting on the measure)	

There was a wide range of test results reported for this project, a sampling of which are shown below. For steam boilers, low-fire efficiencies around 85% and high-fire efficiencies close to 80% should be targeted.

Figure 5 Combustion test analysis



3.2.4 Sequence boilers to maximize plant efficiency

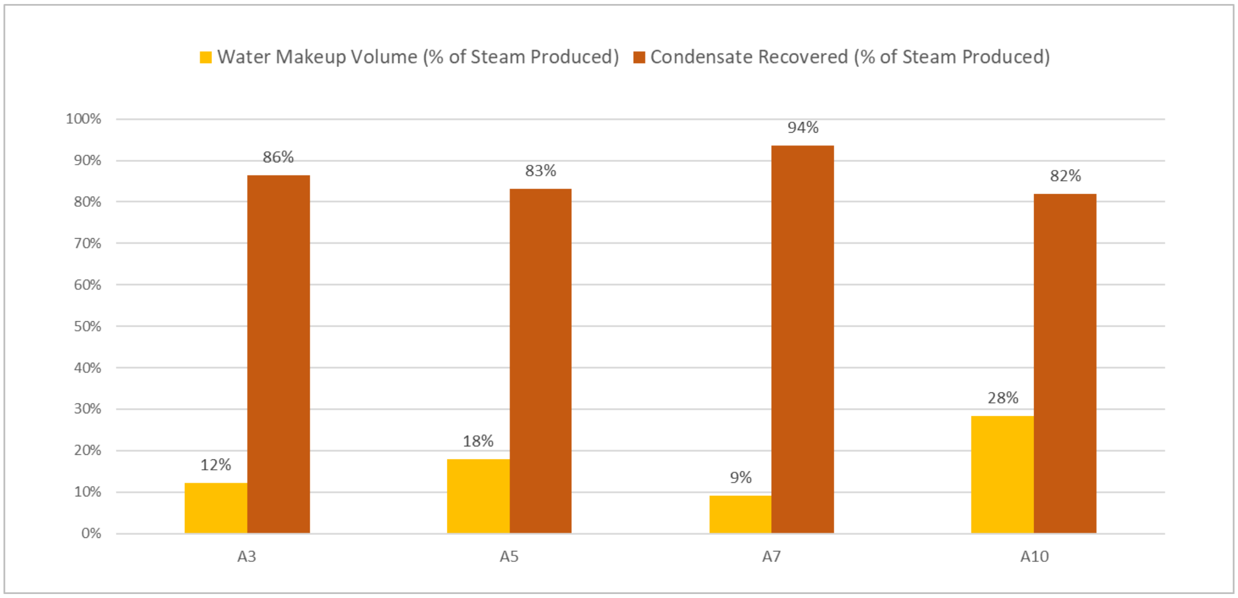
Automatic sequencing of boilers to stay as close as possible to the "sweet spot" efficiency of each boiler is important for maximizing overall plant performance. Section 3.2.2 illustrates how boiler efficiency goes down as firing rate increases, so that (for example) it is more efficient to run two boilers at 40% that one at 80%. Test reports also show which boilers are more efficient across their firing ranges. Boiler plant operation should be under BAS control, and the operating sequence should be programmed to maximize efficiency while achieving approximately equal annual run-times for each boiler.

3.2.5 Increase condensate return, reduce water makeup volume

Maximizing condensate returned to the boiler plant reduces gas and water consumption associated with makeup water and blowdown, as well as lowering chemical use and water treatment costs. Condensate return and water makeup volumes should be metered and continuously monitored so that excessive losses are immediately detected, tracked down and corrected. Condensate return pumps, blowdown, steam traps and steam system vents should be regularly inspected to identify and correct losses of condensate and steam.

Figure 6 shows condensate returned and water makeup volume as a share of steam produced for 4 hospitals which reported these data. Higher condensate return and lower water makeup percentages generally correlate with lower gas consumption.

Figure 6 Condensate and water makeup volume



	CCC	Acute
# of hospitals with recorded data on condensate and water makeup volume	0 (4)	5 (10)
	# of hospitals reporting having the measure (total # of hospitals reporting on the measure)	

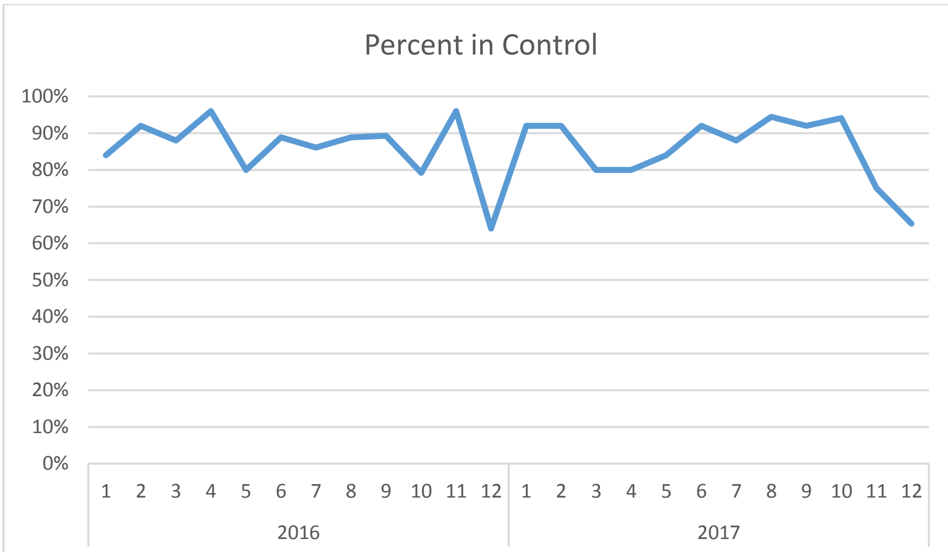
3.2.6 Water treatment

Boiler feedwater needs treatment to remove total dissolved solids and ions that would otherwise form scale and corrode heat transfer surfaces. The selection of water treatment system depends on the boiler type, size, and source water mineral content, and may consist of all or a combination of reverse osmosis, filtration, water softener, chloride cycle de-alkalizers, and deionizers for clean steam applications. Feedwater quality determines how much boiler blowdown or cycles of concentration are required for optimized boiler operation. Maintaining consistently high quality maximizes efficiency and extends boiler life.

Feedwater quality can be monitored by boiler plant operators and water treatment service providers on a daily or monthly basis or can be continuously monitored automatically. Results compared against site-specific control limits produce the key metric of Percent in Control – the ratio of number of times the parameter(s) are within control limits to total number of readings taken. Control limits should be set by a qualified professional following best practices for the water treatment industry referencing 2015 ASHRAE

Handbook — HVAC Applications, Chapter 49 Water Treatment, Deposition, Corrosion, and Biological Control. The ratio should be kept above 80% at all times for ideal plant operation. The statistical validity and effectiveness of this measurement increases with frequency of testing/reporting, with electronic logs or online continuous monitoring providing the highest confidence. Figure 7 shows a typical multi-year trend from an electronic log, with two periods which fell below the 80% threshold requiring attention.

Figure 7 Water treatment Percent in Control



Recommended best practices are to implement monitoring and reporting of Percent in Control, and then consider improvements to the water treatment system and operations with service providers and the hospital's engineer.

	CCC	**Acute**
# of hospitals reporting Percent in Control	1 (5)	5 (9)

# of hospitals reporting having the measure (total # of hospitals reporting on the measure)

3.2.7 Operating logs

Operating logs in use by participating hospitals ranged from hand-written ledgers through Excel spreadsheets to digital platforms which trend and evaluate data entries and provide guidance on remedial action. As well, the scope of data recorded varied widely between hospitals.

The recommended operating log is electronic and capable of trending parameters and flagging out-of-range conditions for remedial action. Such information systems are available from water treatment service providers. Operator training is required to make full use of this capability.

APPENDIX A: DATABASE CONTENTS

GBPS	
Hospital Type	Acute/CCC
Beds	#
Building Area	ft2
Base Thermal 2016	ekWh/ft2
Heating Thermal 2016	ekWh/ft2
Total (2016 Toronto)	ekWh/ft2
Heating BT - 2016	degC
STEAM PLANT	
Main Boilers	#
Capacity (each)	BHP
Economizers	Yes/No
Linkageless Controls	Yes/No
FD Fan VFD	Yes/No
FD Fan HP	HP/boiler
Modulating Control	Yes/No
Step Control	# of stages
Summer Boiler	#
Capacity (each)	BHP
Feedwater Pumps	#
FW Pump HP	total HP (kW)
Steam Pressure	PSI
Night Reset	PSI
Back-Pressure Valves	Yes/No
Boiler Operating Log	Yes/No
Boiler Test Report	Yes/No
Boiler Efficiency (Low)	%
Boiler Efficiency (Med)	%
Boiler Efficiency (High)	%
Pre-treatment Equipment	Select: a. Softener; b. Softener + Polisher; c. Softener + Chloride-Cycle Dealkalizer; d. Softener + Polisher + Chloride-Cycle Dealkalizer; e. Reverse Osmosis
Concentration Cycle	conductivity ratio
2016 Water Makeup Volume	gallons
2016 Steam Produced	lbs
2016 Condensate Returned	gallons
Water Quality Data (reports, logs)	Select: a. Vendor Service Reports Only (at least 12 months); b. Vendor Service Reports + Operator Log Book Data; c. Vendor Service Reports + Operator Log Book Data + Online Controller Datalog File
2016 Percent in Control	%

Database contents – continued

HOT WATER PLANT	
Boilers	#
Capacity (each)	BHP
Linkageless Control	Y/N
FD Fan VFD	Y/N
Boiler Test Report	Y/N
Boiler Efficiency (Low)	%
Boiler Efficiency (Med)	%
Boiler Efficiency (High)	%
BAS Trend Logs	
Boiler status	On/off
Boiler loading	%
Steam Pressure	PSI
Primary HW temperature	degF
Loads Served	
DHW	Steam or HW Plant
Sterilizers	Yes/No
Kitchen Equipment	Steam equipment Y/N
Perimeter Heating	Steam or HW Plant
Ventilation Reheat	Steam or HW Plant
- Off in Summer?	Y/N
Glycol Heat Exchangers	Y/N

APPENDIX B: BOILER PLANT BEST PRACTICES ACTION CHECKLIST

For Greening Health Care members, the latest working version of the checklist can be found under Documents on the Program Website: ghc.enerlife.com

Hospital organization:	Facility:
Completed by:	Date completed:

Period of data:

	Actual ekWh/ft2	Target ekWh/ft2	Savings Potential	
			%	$/yr
Base Thermal				
Heating Thermal				

Action		Already Implemented	Planned	Consider	Reject/ NA	Details
Guide Section #	Name					
	Plant Configuration and Design					
3.1.1	Install flue gas economizers					
3.1.2	Install summer boiler					
3.1.3	Design combination hot water and steam boiler plant					
3.1.4	Specify/Retrofit linkage-less controls & O2 trim					
3.1.5	Specify/Retrofit modulating burner control					
3.1.6	Specify/Retrofit VFD on forced draft (FD) fan					
3.1.7	Specify/Retrofit VFD on feedwater pump					
3.1.8	Install back-pressure valves					

Action		Already Implemented	Planned	Consider	Reject/ NA	Details
Guide Section #	Name					
	Plant Operation and Control					
3.2.1	Reduce/reset steam pressure and primary HW temperature					
3.2.2	Implement steam line isolation					
3.2.3	Perform boiler testing and tuning					
3.2.4	Sequence boilers to maximize plant efficiency					
3.2.5	Increase condensate return, reduce water makeup					
3.2.6	Upgrade water treatment to optimize % in control					
3.2.7	Introduce electronic operating logs					