

Boiler Energy Conservation Performance Studies in a Commercial Facility: Setting the Stage for Cogeneration and Distributed Generation

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ABSTRACT

Growing attention is now being paid to energy conservation that was once considered insignificant for energy resource development. An energy efficiency study on the heating system for a commercial facility was performed using the BIN method that can be adopted by energy management practitioners. Such data-based method calculates the load and energy savings for the recommended boiler replacement. Energy consumption data, measurements and flowcharts developed were used to study the operating costs and energy savings for the facility. The study shows that the method can be used to decide if a boiler or heater replacement is worthwhile. Moreover, this study sets the stage for further energy management and reliability investment in the form of cogeneration of heat and power (CHP) or distributed generation (DG). It was determined in this study that using the prescribed strategy will result in significant energy savings for the investments made. Finally, basic data needed for cogeneration analysis resulted from the study.

Key Words: Commercial building heating, boiler replacement, BIN method, CHP data

INTRODUCTION

One of the most promising cost reduction and profit improvement programs for effectively dealing with energy shortage is to retrofit

energy efficiency measures followed by a distributed generation (DG) scheme. In the face of energy supply uncertainty and fuel price volatility, this is now one of the most important approaches of choice for meeting the needs of energy requirement. Demands for greater efficiency in energy consumption has made the boiler equipment to be a significant factor in the efforts at energy conservation in buildings. The HVAC system is amongst the largest consumer of energy in commercial buildings. In the boiler, water is converted to steam or hot water in a series of tubes connecting the water and steam drum. The source of heat for the steam drum of a boiler is combustion of fuels, such as wood, coal, oil or natural gas. Lately, cogeneration or the concurrent generation of heat and power has been considered for kinds of buildings: Restaurants, hospitals, malls, apartment buildings, hotels, airports, etc. Thus, a comprehensive approach to evaluating cogeneration systems for residential and commercial buildings is given by Lozano and Ramos [1].

Computer simulation has contributed to the movement towards modeling energy consumption and conservation in buildings. However, building owners and engineers pay very high costs to use this method because of sophistication and large inputs required to be fed into computer programs. Sometimes, the approach requires the use of complicated modeling software. A significant disadvantage of this approach is that despite the sophistication, the modeling sometimes is still time consuming and requires a trial and error process which contributes to the initial cost of the project. Also, unpredictable parameters such as changing demand pattern can cause computer predictions to vary with actual usage. Vikhansky et al. [2] used a three-dimensional computational fluid dynamics code to study the performance of a wall-fired boiler. The results of the study showed that connecting plant measurements with 3-D furnace modeling could be a cost effective method for design and optimization. Procell et al [3] reported on the outcome of an energy audit and energy-conservation measures implemented on the physical plant and buildings of a high school. An energy modeling computer simulation program was employed in the project. A lighting retrofit, installation of motion sensors, boiler replacement and the installation of an energy management system were recommended in the report for significant reduction in energy costs.

Related previous reports in the area of boiler replacement are also available. Acton [4] discussed new directions in energy technology and reported that selecting the correct type of boiler for a given application

can produce substantial savings in both initial equipment cost and years of operating costs. The report further indicated that proper insulation and installation of heat recovery systems can reduce operating costs. Also, reasonable maintenance of the boiler equipment can reduce energy costs, and replacement equipment costs because of efficient plant operation. Fiorino [5, 6] reported on a real-time project of replacing an old, steam boiler with a new high-efficiency system, for a semiconductor-manufacturing complex. The combined initial cost of the various steam conservation measures and boiler plant efficiency measures was about \$1.37 million, and the combined annual fuel and energy cost savings resulting there-from was determined to be about \$1.3 million per year. The replacement and implementation of the recommended measures resulted to a 35% reduction in annual steam costs. This yielded a simple payback period of 1.1 years and an annual return-on-investment (ROI) of 95%.

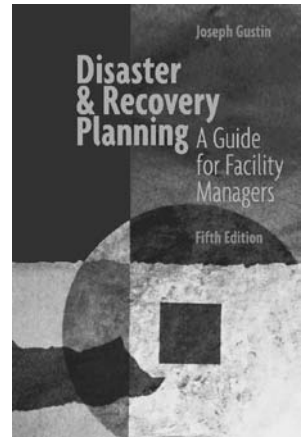
Hurst [7] reviewed two recent boiler replacement and retrofit projects. In the first project, a completely new replacement boiler plant was installed at a hospitals complex. The new boiler plant contained three new package boilers. The boilers were equipped with low-NO_x parallel flow burners that were designed to utilize Induced Flue Gas Recirculation (IFGR). Also included in the plant were new makeup, feedwater, and condensate systems, as well as a new Distributed Control System (DCS). In the second project, two new boilers were installed to replace existing boilers at a university's central heating plant in Ithaca, New York. Provision was made for the removal of two existing boiler feedwater pumps and subsequent installation of a new steam turbine-driven feedwater pump. The installation of a new pressure reducing-desuperheating station, and the expansion and upgrading of the DCS, as well as extensive building modifications were recommended.

Fiorino [8] examined cost-effective efficiency advancements that were implemented during a recently completed boiler plant replacement project in a large semiconductor manufacturing company. The boiler replacement consisting of four water-tube boilers burning natural gas was effected because the annual fuel and power costs were approaching the initial cost of the industrial power plant. Gustafsson and Karlsson [9] studied energy conservation and retrofits in multifamily buildings. The report presented a case study showing that it was optimal to replace the existing heating system with a natural gas boiler combined with attic floor insulation. A sensitivity analysis performed in the study showed

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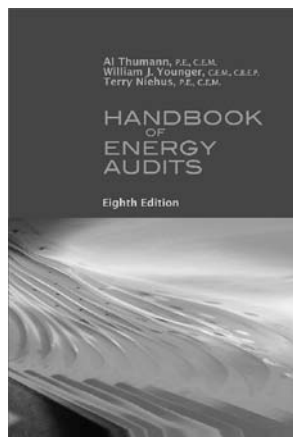
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that the solution recommended was reliable even in the face of rising natural gas costs.

In addition to assessing, proposing and retrofitting energy efficiency measures, these authors consider all of the above constitute essential pre-work to evaluate the potential for cogeneration or distributed generation options in any facility with significant combined heat and power or CHP needs. Next, with energy conservation being significant today, there is the need to develop simpler ways for reviewing and upgrading older energy inefficient installations that were made when energy costs were excessively low so as to take advantage of the resulting energy conservation. In this present study, a strategy for energy conservation with boiler replacement for improving energy efficiency in a commercial facility was developed. The facility consists of three multi-level buildings. The model developed applies a simplified method along with the *bin* method and energy data for the commercial establishment and calculates the current consumption and future operating costs and savings for an upgrade system. The method is suitable for commercial and industrial buildings with unusual operations as well as houses with passive heating/cooling and high-mass thermal storage. It is simple enough for calculations to be made manually if desired. Results show that using the strategy would result in significant energy savings for the investments made. Next, data collected before-and analysis of results during commissioning and after implementing efficiency measures—are suitable to understand the building's combined heat and power needs. Consequently, such data can be part of the inputs needed to evaluate the facility's cogeneration potential.

METHODOLOGY

The commercial facility studied here consists of three buildings with a gross area of 31,227 square meters (336,000 square feet). One of the buildings has nine levels, and a total approximate floor area of 12,825 square meters (138,000 square feet). The second building has eight levels, and a total approximate floor area of 10,967 square meters (118,000 square feet). The third one is a six-storey building that has a total floor area of approximately 7,435 square meters (80,000 square feet). The businesses in the buildings include engineering consulting, software development and use, marketing, accounting, and other ventures.

The building spaces are used for purposes, such as offices, conference rooms, cafeteria, copy/print rooms etc. The occupancy period is mostly between 8.00 a.m.-7.00 p.m. during the normal work week and mostly unoccupied during weekends and holidays. Miscellaneous appliances in the buildings include fans, heaters, coffee machines, microwave ovens, kitchen equipment etc. Heating and cooling are provided from a central HVAC plant that houses the boilers and chillers from which chilled water and steam are distributed in the buildings through pipes. Steam is circulated for perimeter heat (by steam radiators), and through the steam-heating coils in the air-handlers to provide zone comfort. Hot water heaters located in different parts of the buildings provide hot water for the bathrooms and cafeteria. Different air handlers in the penthouse of each building circulate air to provide adequate ventilation and hot/cold air to the buildings.

The Bin method was used for the boiler energy calculations in this project. The method is suitable for commercial and industrial buildings with unusual operations as well as houses with passive heating/cooling and high-mass thermal storage. It is a multiple-step method that is simple enough for calculations to be made manually if desired. The idea is that 5°F temperature ranges, or Bins are established for the location of the buildings. The heating and/or cooling load was calculated at each temperature bin occurring at that location. The load is determined in Btu or (W) and then multiplied by the number of hours during which the associated bin condition occurs. The results are used to obtain the annual Btu or (W) at each bin. Then all the Btu energy is added together to arrive at the total Btu energy use for the year.

The Department of Defense (DOD) Bin weather data for Seattle, WA were used for this, thus contributing to determining the energy gains/losses for the buildings in the facility. The data were averaged over several years' worth of hourly data. Hourly temperature data were apportioned in three, eight-hour time blocks per month. The first hour of building operation was made to correspond to the first hour of the bin and the last hour of building operation corresponded to the last hour of the bin.

Data gathered from the commercial facility included:

- (1) Detailed data specifications for the HVAC facility.
- (2) Water temperature in the primary and secondary loop—using infrared temperature gun.

- (3) Existing load, air-handling unit and perimeter heating equipment schedules.

The calculation steps involve:

- (1) Determination of the switch over temperature for heating from energy data.
- (2) Calculation of the total number of hours at each BIN temperature.
- (3) Determining the current demand and consumption by the heater.
- (4) Calculation of the power and off peak consumption of the system.
- (5) Calculation of the appropriate savings

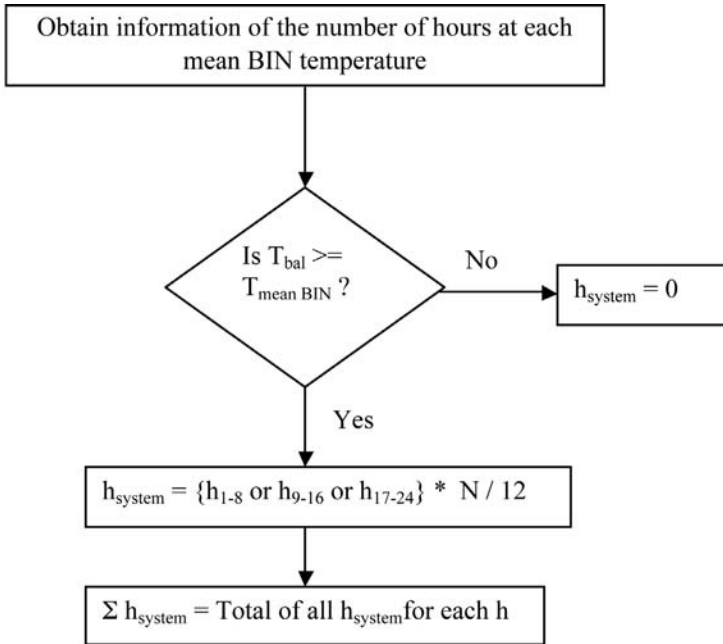
Boiler upgrading involves changing the currently existing electric heating, with a new gas fired boiler to take advantage of lower gas prices compared with electricity and peak electricity costs.

Next, we conducted the system operation modeling and simulation using BIN weather data. The following section summarizes the algorithm of such analysis, in three stages:

- Find the number of operating hours for the system using BIN data—Flowchart 1.
- Model the existing system using the BIN method—Flowchart 2
- Model the proposed system using the BIN method—Flowchart 3

ALGORITHM AND RESULTS

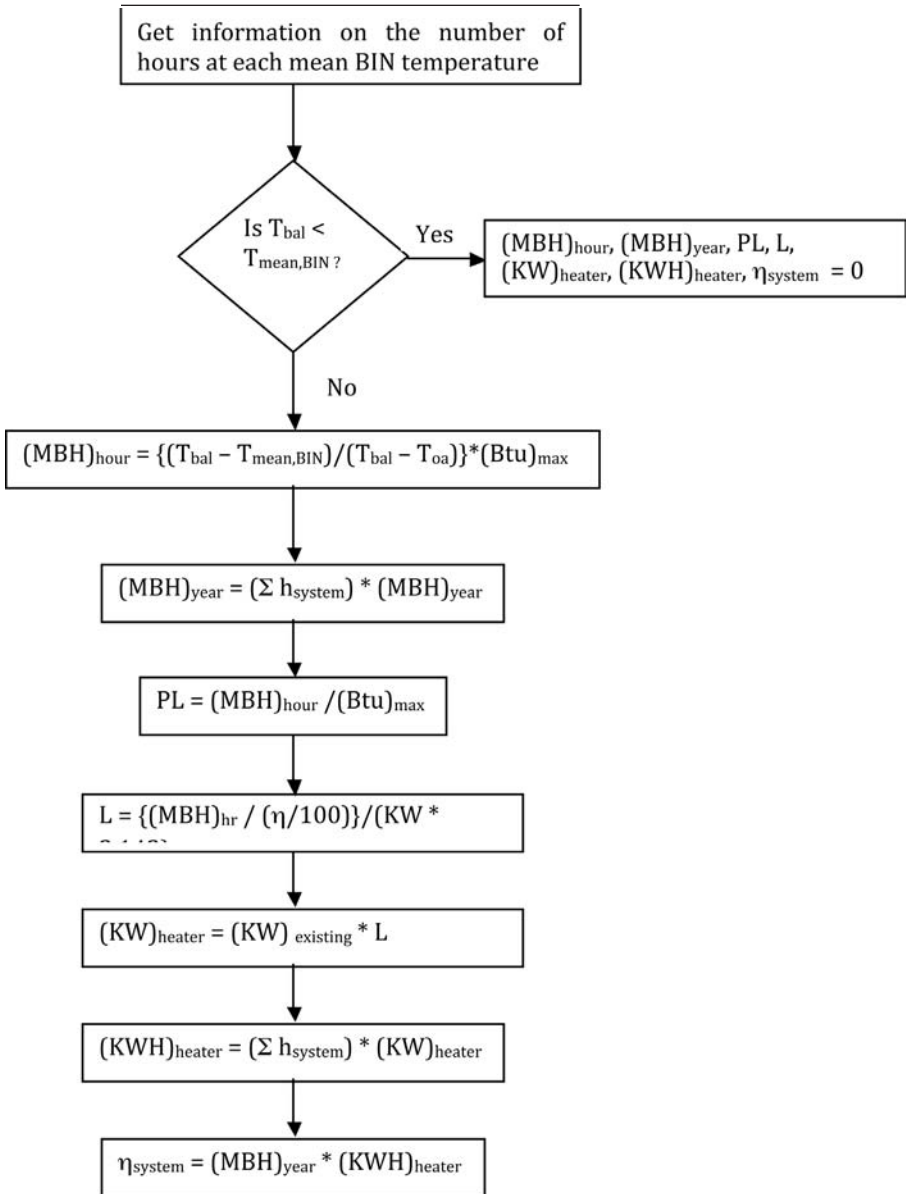
The relevant equations and procedures constitute the basis of the computational method developed in and for this study. An algorithmic approach is outlined by the next three flowcharts. SEE the *Nomenclature* section for terms and definitions. Since the calculations can be done and plotted on spreadsheets, MS Excel was used in this study. Flowchart 1 shows the procedure for determining the total number of hours for the system operation. Flowchart 2 shows the procedure for determining the kilowatt-hours and efficiency of the existing system. Flowchart 3 shows the procedure for obtaining the kilowatt-hours for the proposed new system.



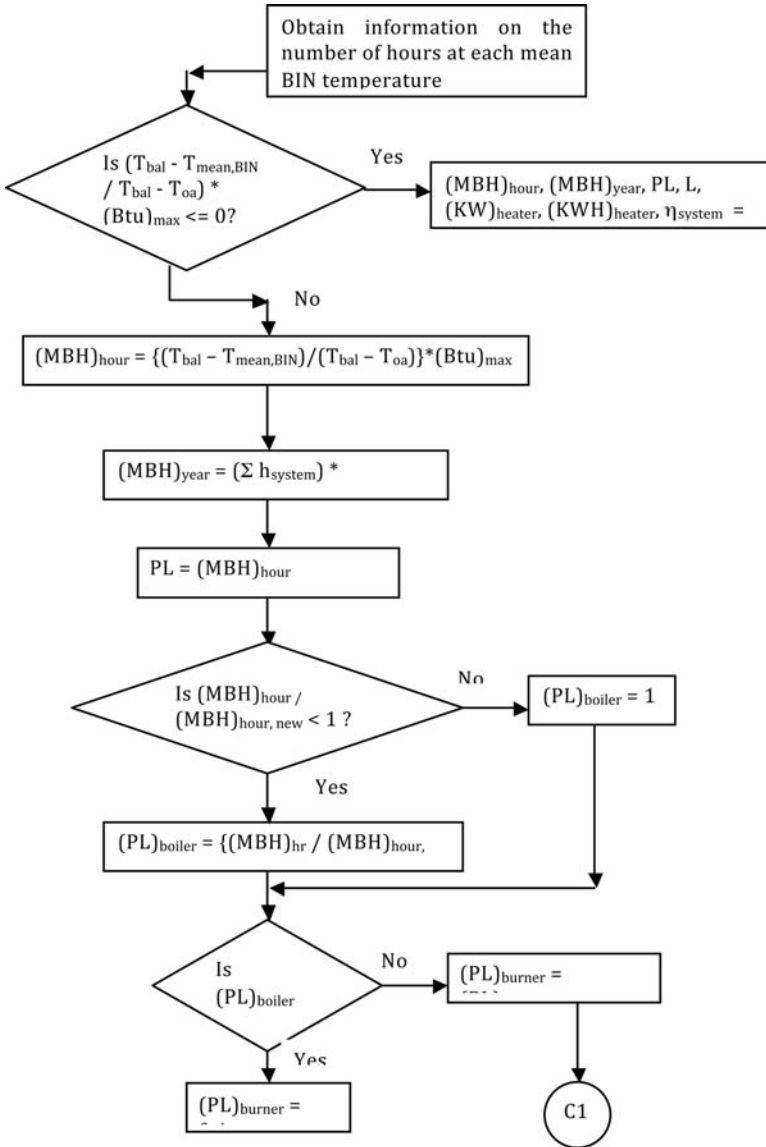
Flowchart 1. Used to find the total number of hours for the system

Figure 1 is a plot showing the cost savings for the boiler replacement. The graph contrasts the present cost and future cost (the cost after implementation of the recommended electricity cost and gas for the burner replacement) for the system. It also can be seen from the figure that there will be substantial savings in energy cost with the boiler replacement particularly within the range of ambient mean temperatures between 20°F to about 55°F.

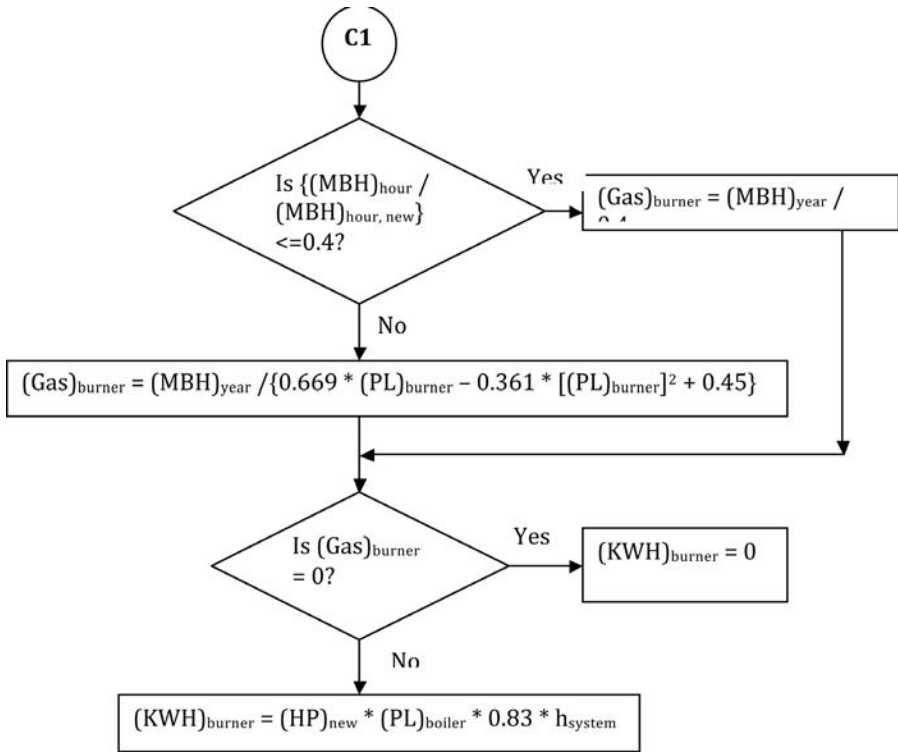
The existing system, which runs on electric heating, was found to be far less cost effective than the proposed replacement. The proposed system is gas fired and pays for gas and electricity consumption but not power demand cost. Thus the new system can realize as much as 41% savings. Such savings can help fund future cogeneration; which in turn will realize more profits. Alternatively, we should follow up by evaluating cogeneration of heat and power as more comprehensive heating, cooling and on-site power supply option.



Flowchart 2. Existing System



Flowchart 3. Proposed System



Flowchart 3. Proposed System (Cont'd)

SUMMARY OF RESULTS

The following are some of the relevant results obtained from the study for the facility:

Annual present electricity usage	:	107,844 kWh
Annual electricity cost	:	\$1897
Annual gas usage in new system	:	1810 therms
Annual electricity usage for the new system	:	496 kWh
Proposed operating cost of boiler	:	\$1116
Total savings (gas + electricity)	:	\$780
Percent savings (gas + electricity)	:	41%

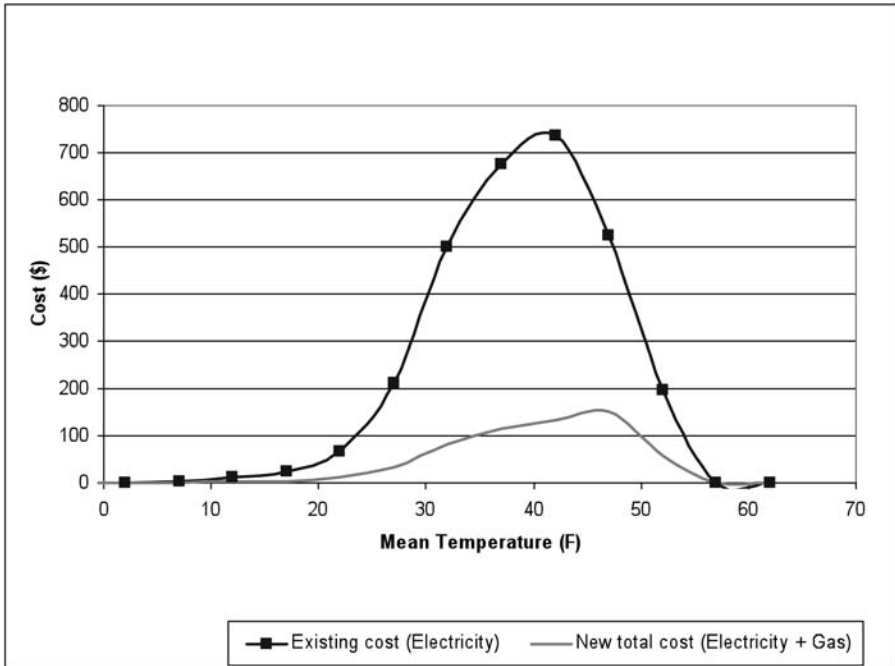


Figure 1. Cost Savings for Boiler Replacement

CONCLUSION

This study is on boiler performance energy conservation in a commercial facility. For a number of reasons, there is a need to develop simpler ways for reviewing and upgrading older energy inefficient installations made when energy costs were excessively low to take advantage of more efficient technologies. A methodology for calculating the existing consumption, future operating costs and savings obtained from recommended boiler upgrade was developed in the study. The model applies a simplified approach along with the BIN method and energy usage data at a commercial facility. Flowcharts, which explain the calculation procedure for the different attributes, were developed. The use of flowcharts, graphs and equations proved to be useful for analyzing the energy saving strategy. The calculations can be performed and charted using spreadsheets. User-friendliness can be added with Graphical User Interface (GUI). The method is suitable for commercial and industrial buildings with unusual operations as well as houses with passive heat-

ing/cooling and high-mass thermal storage. It is simple enough for calculations to be made manually if desired.

The proposed system, evaluated with the method developed in this study, can realize significant savings (41%). However, both as an alternative or as a sequel to the system proposed here, we shall evaluate a system-wide solution based on a cogeneration scheme. While the underlying study focuses on the heating (boiler) load of the building, a similar approach can be applied to assess the cooling (chiller) load of such a building. Future articles will consider (a) using the method herein to assess the cooling and other power loads, and (b) to combine all loads heating, cooling and other electricity loads for evaluating various CHP options such as district heating and cooling.

NOMENCLATURE

AArea

(Btu)_{max} Maximum Btu/hr for the entire system = 84.5Btu/hr

(Gas)_{burner} Gas consumption of burner (therms/year)

h_{system} System hours

h_{1-8} Hours in the BIN at that particular $T_{\text{mean, BIN}}$ from 1-8 hours

h_{9-16} Hours in the BIN at that particular $T_{\text{mean, BIN}}$ from 9-16 hours

h_{17-24} Hours in the BIN at that particular $T_{\text{mean, BIN}}$ from 17-24 hours

(HP)_{new} HP of new boiler

(KW) KW of existing boiler

(KW)_{heater} Heater load (KW)

(KWH)_{burner} KW-hour consumption of burner in proposed system

(KWH)_{heater} KWh of heater (KWh)

LLoad

(MBH)_{hour} Metric Btu/hr of existing boiler

(MBH)_{hour, new} Metric Btu/hr of the new boiler

(MBH)_{year} Metric Btu/year

NNumber of months boiler needs to run

PLPercent load

T_{bal} Balance temperature for switch-over

$T_{\text{mean, BIN}}$ Mean BIN temperature (°F)

T_{oa} Outside air temperature F

t_{start} Start time = 1

t_{stop} Stop time = 24

η Efficiency of existing boiler (1 to 100)

η_{system} Efficiency of the existing system

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