Unified Framework for Energy Monitoring and Demand Based Optimization for Commercial Buildings – IoT based Enterprise Implementation and Beyond

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***Abstract*—*The importance of efficient and optimal use of energy is continually on the rise. With depreciating natural resources and increasing demand for energy, it has become imperative for corporate buildings to monitor and optimize the energy usage. The effective operation of commercial buildings is practically difficult as the conditions change in dynamic manner. In the current communication, different assets that contribute to energy bills are analyzed. The assets include Chillers, Air Handling Unit (AHU), Uninterrupted Power Supply (UPS) and Lighting which are the chief contributors to energy bills. Algorithms for demand based optimization of the assets were developed. Time series analysis was used for forecasting the demand on the assets. Occupancy pattern and head count were considered as demand for the assets. Four slots were considered for demand forecasting which include weekday, weekend, and days before and after holidays, holidays before and after weekend. With hour on hour forecasting for the demand, scheduling recommendations for chillers were provided .Based on peak load consumption, rightsizing of UPS and potential energy savings recommendations to minimize the loss were provided.*

Similarly, health index model for AHU was developed which identifies the wastage for AHU in the building. Based on occupancy forecasting AHU can be made to switch on/off. The same model was used to identify the wastage for lighting. Based on occupancy forecasting pre-determined switch on/off of appliances was scheduled in a semi-automatic manner. The unified generic framework algorithms were developed using Python 2.7. Deployment and testing were performed for close to 60 buildings and the results for energy savings were found to be satisfactory

Keywords*— *Energy optimization for buildings, Chillers, AHU, UPS and Occupancy based demand forecasting

I. Introduction

There is a growing interest to reduce building energy consumption through increased sensory data and increased computational support [1]. This interest is largely motivated by the significant percentages of global energy consumption attributed to buildings. Energy management refers to optimizing significant energy consuming assets in buildings. While there is umpteen research in optimizing energy generation and distribution, it is the demand side that receives increasing attention in industrial research [2]. The goal for sustainable energy for society is in the forefront of public interest, and it is a high priority for decision makers. Though building management systems (BMS) has the provision of real time input of dynamic factors including occupancy, occupant preferences, occupant actions, ambient conditions and decisions systems still lack intelligent reasoning to deal with such dynamic and distributed input is a challenge [3]. With different ages and types of buildings viz., rented, leased and owned, the challenge to optimize becomes complicated. Also with the challenge that comfort conditions in the interior of a building needs to be maintained, it is imperative that the problem of energy conservation becomes a multidimensional one [4]. Living space thermal comfort, with the building housing data centers, temperature regulation is a multivariate problem having no unique solution. The objective of the system should include high comfort level, air quality, efficient operation of assets and energy savings [5,6]. The combined process for the above systems requires optimal performance of almost every subsystem, under the basic assumption that each operates normally in order to avoid conflicts arising between users' preferences and the simultaneous operations of these control subsystems. Mathews et al. [7] developed cost efficient control strategies to achieve optimal energy and acceptable comfort conditions. With above background research, a unified solution was arrived, as elaborated in the following sections

II. Solution Architecture

Jayakumar et.al, [8] has proposed the smart gateway reference architecture for Industrial Internet of Things. By interfacing different energy meters for appliances, a unified architecture was proposed. Energy (kWh) from smart meters were read and sent to central server for processing. The processing includes data cleansing and missing value treatment with standard techniques. Once monitored, base lining and benchmarking were carried out followed by operational optimization i.e. wastage elimination and asset performance improvement. Significant energy consuming assets were identified which includes Chiller on the supply side, AHU, Lighting and UPS for demand side.

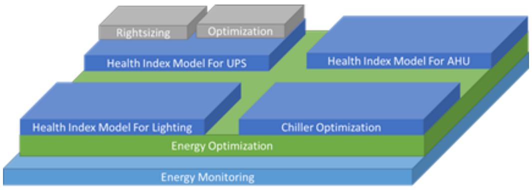

Figure 1: Energy Model Block Diagram

III. ENERGY SAVING SOLUTION S

A. *OPTIMIZED CHILLER SCHEDULING*

The data model for Optimized Chiller scheduling is generated using operational constraints, forecasted demand, secondary loop delta_T and a power model, which determines the optimal power consumed by chiller. The assumptions include no heat gains/losses due to pipes and insulation from chillers to AHUs. Flow rate of water in the Primary loop is captured as meta data as mentioned in the design provided by OEM. The thermal inertial time of the Chiller is considered to be less than 15 minutes. All the Chillers systems are considered to be identical.

Common header supply temperature varies between 8-10 degree Celsius, minimum chilled water supply temperature as 5 degree Celsius, total chiller plant cooling load is equal to building demand, Maximum of 2 WCCHs under operation at any point in time, minimum up-time and down-time for any chiller is 30 minutes

Cooling Demand Forecasting:

The cooling load at any time is the sum of individual chiller instantaneous loads operating at that time. ΔT refers to the difference between chilled water supply and return. A data driven approach to describe the thermodynamic system was adapted. ΔT was used to estimate the flow rate in secondary loop. The chiller sequencing is parameterized on ΔT values of 40C and actual ΔT of tested day. It may be noted that it is always desirable to have ΔT close to design 10 to 12 degree Celsius. Forecasting is based on the obtained hourly historical TR (Tons of refrigeration) for each chillers. The total facility TR for an hour is equal to the sum of TR of all the chillers in the Facility. TR for the next day for each hour is forecasted using Statistical Analysis of Time Series, Autoregressive Moving Average (ARMA) Model.

Chiller power was tested for different chiller power models available in the literature .Training on the historical chiller data such as Supply Water Temperature, Ambient Temperature (for Air cooled Chillers), condenser Inlet Water Temperature (for Water Cooled Chillers), chiller load and power consumption. Gordon-Ng physical chiller model preformed best at accuracy of 83% for air cooled and 93% on water cooled chillers, and the same has been used in the sequencing algorithm. A branch and bound technique was used for scheduling the chillers. The algorithm with the constraints provided by the admin operators was found to be satisfactory.

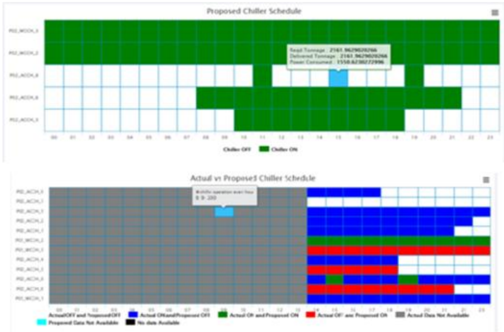

Figure 2: Optimized Chiller Scheduling

B. *HIM AHU*

It is an Energy Saving application used to identify the wastage in AHU operation energy by comparing against occupancy in each of the facility as and where the meters are available. Energy and occupancy correlation shall be performed using multiple discriminant analysis. The application generates reports based on the date field selection fed by the user from UI provided. Data was taken from sensor metadata and observation of AHU and occupancy meters. It does not take into consideration the anomaly from data source. The granularity of the application is on day to day and week on week basis. Specific operation were performed upon the data retrieved from the DB. Matching of the time stamp of the occupancy and energy data was performed and the corresponding data sets were used for analysis. Slot wise threshold was computed. The slots include:

a. Weekday 9 AM to 8PM – Slot 1

b. Weekday 9 PM to 8 AM – Slot 2

c. Weekend 9 AM to 8 PM – Slot 3

d. Week end 9 PM to 8 AM – Slot 4

If Potential Savings Percentage ideal is greater than the computed acceptable percentage, the energy was quantified as potential savings. The sum of such energies would be potential energy savings for that floor.

AHU Operating pattern i.e. switch on and switch off time was changed based on the tool recommendation and a savings of 5% was obtained.

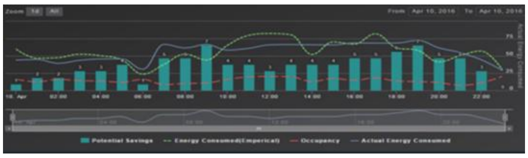

Figure 3: HIM AHU Report

C. i AHU

The purpose of iAHU (Intelligent Air Handling Unit) solution was based on first principles modelling of ambient temperature, ambient relative humidity, real time occupant movement between rooms, return air relative humidity, return air temperature to set the temperature of AHU, there by achieving savings by optimizing the energy consumption in AHU with maximum occupant comfort.

The following parameters was used as input for analytic model

- Return Air Temperature
- Return Air Relative Humidity
- Supply Air temperature
- Supply Water temperature
- Occupancy Comfort

The relationship between the variables (occupancy, return air relative humidity, humidity) are achieved. Z-test and one –factor ANOVA is used for quantifying the relationships among variables.
ANOVA table helps to understand that test statistics significance among the variables

Table 1 : Sample ANOVA Table

Source	SS	DF	MS	F
Treatments	27.897	2	13.949	9.59
Error	17.452	12	1.454	

Upon observation, the sample data was correlated and the relationship between the variables (set point, AHU Energy – Occupancy, Energy – Set Point, Chilled Water Temperature etc.,)

$$\rho = 1 - \frac{6 \sum d_i^2}{n(n^2 - 1)}.$$

Where **rho** is the Sperman correlation, $\mathbf{d_i}$ is the distance between ranks and **n** is the number of samples

By varying the set points, at different dates, occupancy comfort was obtained and analysis was performed.

It was observed that for a RARH of 60- 70% and a RAT of 24^0C , occupancy comfort was maximum. Also for set point of 25^0C , occupancy comfort was observed.

The energy is quantified as potential Energy savings. The sum of such energies would be potential energy savings for that facility. A savings of 5% was achieved.

D. HIM UPS

HIM-UPS (Health Index Model - Uninterruptible Power Supply) is an Energy Saving application used to identify the wastage in UPS energy by comparing against occupancy in each of the facility as and where the meters are available. HIM-UPS (Health Index Model - Uninterruptible Power Supply) developed using Python as a part of Energy Saving initiative. This application shall be deployed to identify the wastage in UPS in each of the facility. The application accepts a configuration file (.csv file) as input and provides the results potential wastages as output reports as charts, web based HTML files.

HIM UPS Application is to identify the potential energy saving in the UPS front and provide useful insight for admin managers and operators. This has two categories:

- UPS rightsizing for a given facility
- Wastage / Potential Savings of UPS in load side.

1. The peak load is computed for the given day, by averaging the hourly data from Database

2. The right sizing for the UPS is provided as two parts follows:

a. The computed recommended capacity (N) is compared with the available UPS (UPS Details.csv) and the best possible combination to achieve the recommended capacity shall be provided. A sample example is shown below:

If the recommended capacity (N) is 225kVA and the available UPS is 4 then the suggestion from the application would be 80(kVA)*4. The number 80 kVA would be obtained from UPS Sizes.csv

b. Without changing the size of UPS in the facility, the best combination to achieve the recommended capacity (N) will be provided. Based on the recommendation, the additional UPS may be removed from the facility, as per the admin's discretion. The sample calculation is as follows:

If the recommended capacity (N) is 225 kVA and the available UPS is 160kVA *4, then the suggestion from the application would be to remove one 160kVA UPS from the circuit.

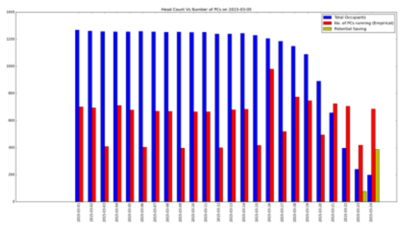

Figure 4: HIM UPS Report

IV. CONCLUSION

With the proposed architecture of building energy analytics algorithm on top of data acquisition layer, energy saving of 5% achieved. The significant energy consuming assets were identified. Proper metering was identified. Data was collected using industrial gateway at a interval of 15 minutes. Analytical models were developed for Chillers, AHU, UPS. Intelligent Air Handling Unit models were developed for savings. Energy forecasting models were developed which were used for trading. Future steps include enhancing the model with constraints viz., losses in pipes, library details for desktop and server UPS.

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