Automation in Industrial HVAC Systems for Energy Efficiency – Case Study Analysis

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Abstract:- **According to the Department of Energy, HVAC systems are responsible for about 40% of the total energy consumption. Increasing the energy efficiency of these systems can radically reduce the energy consumption. This paper aims to compare two case studies using different automated HVAC systems in terms of their energy efficiencies.**

Previously, HVAC systems were manually operated and monitored which made it quite tedious and inefficient. In the recent decades, integrating HVAC systems with IOT has turned out to be quite effective and efficient. Building automation systems and Building energy management systems are two such systems which use smart sensing networks.

This paper analyses two case studies based on the different energy efficiency measures and performance of the automated HVAC systems. Further it discusses the importance of automation in increasing the energy efficiency, facilitates easy maintenance and makes the system cost effective.

Keywords:- *Heating Ventilation and Air Conditioning; Intelligent Building Management System; Building Automation System; Internet of Things; Programmable Logic Controller.*

I. INTRODUCTION

The term energy efficiency refers to an alternate process, equipment or method producing a product or service with less energy, by implementing the changes largely on the availability of technology and economic justification. There is an inextricable link between the energy efficiency and the building energy use which is majorly influenced by a variety of parameters such as; micro and macro-climate, site location, building function, occupancy and use, building configuration, building orientation, building envelope design considerations and building materials. The energy management in buildings can be approached using 3 main considerations:

1. The Building Site – The choice of site influences the climatic conditions, building orientation, plants and topographical advantage, etc in order to have optimal energy use.
2. The Building Envelope – The building envelope determines the influence of site conditions on the building occupants by means of providing shade to reduce solar heat gain, optimizing building volume, area and layout for energy efficiency, etc.
3. The Building Systems – These systems supplement both the site and envelope, majorly influencing lighting, heating and cooling systems together known as HVAC systems.

HVAC system is a technology used to ensure indoor, thermal comfort with acceptable indoor air quality. It is designed based on the principles of thermodynamics, heat transfer and fluid dynamics.

According to Forbes, the implementation of automated HVAC systems and smart energy management systems reduced the total energy consumption by 75%.

In the recent years, Intelligent Building management systems are being implemented in industries which not only control HVAC, but also centrally monitor the lighting, elevators and life safety systems along with maintenance, administrative and business functions. The automated HVAC systems use PLCs and web-based applications to control the smart sensors. These smart sensors control the temperature, pressure, humidity, air-flow, enthalpy and indoor air quality which help ensure ambient conditions in the indoor environment.

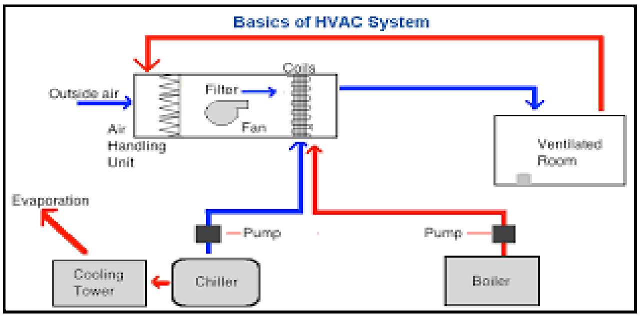

Fig 1:- Conventional HVAC system

The purpose of this paper is to analyze the different automation strategies used in the case studies and to compare their performance in terms of energy efficiency. These automated HVAC systems when combined with AI and self-learning algorithms makes it more energy efficient and cost effective.

Fig 2:- Automated HVAC system

II. LITERATURE REVIEW

A. Research on building energy management in HVAC control system for university library.

This paper is a research on building energy management for University Libraries which are usually high energy consuming buildings on campus. Combining the building automation technology, heating, ventilation and air-conditioning (HVAC) has been proposed by field bus communication. This research uses a simple example from the field of electrical technology, variable cooling water system is taken as example to show the function of optimal start/off control, emergency protection and linkage control via the closed-loop feedback system in the frequency converter and programmable logic controller and three-layer bus network architecture to build the automatic control system diagram for the library. Further the paper discusses the energy consumption of HVAC systems in summer focusing on the improvement of occupant comfort, efficient operation, and supervisory control strategies have been proven to reduce energy consumption and application of automatic control technology improves the performance of operation.

B. Programmable Logic Controller for HVAC Application

This paper describes the design of the control panel for HVAC applications based on control philosophy by which the PLC panel specifications and load calculations are done. The process starts from preparation of documents like Control Philosophy, Logic Flow Chart, IO list, specification, and layout. This paper also covers design stages from overview of general HVAC process, documentation for PLC design, actual manufacturing and testing, implementation and commissioning. An existing methodology of the HVAC control system with PLC is used to understand the working of the automated system and then further provides a scope to work on implementing an integrated advanced alarm and notification system in the plant. Hence provides an insight to future researchers, working towards the safety cautions.

C. Nonlinearity Approaches Based on Fuzzy Cognitive Maps in HVAC systems

This paper is a review on different control techniques of HVAC systems which conveys the hard control methods that are widely used in the industries but also discusses the importance and effectiveness of implementing soft control and fusion control groups, which has better results. This paper majorly discusses the hybrid Multiple-Input and Multiple-Output (MIMO) non-linear system and the Model Predictive Control (MPC) method for linear systems, which is a combination of fuzzy logic and neural network methods resulting in an optimization solution. The Fuzzy Cognitive Map (FCM) control method which gives faster and accurate results for complex problems which considers the building automation parameters as well. The FCM method is better than MIMO and MPC methods as it uses graphical notations to interpret results hence making it simple and familiar. Thus, the application of FCM as a control system can contribute in the expansion and improvement of more autonomous and intelligent control systems.

D. A survey of Control Technologies in the Building Automation Industry

This paper describes a survey on building automation industries using advanced control technologies in infrastructure such as communications, processing power and data storage. The existing and emerging technologies are reviewed for control in the building automation industry and also discussing the specific issues in adopting new control technologies. In particular, communications and networking technology has evolved considerably in terms of bandwidth and reliability with decreasing operating cost, relative costs of processing and storage capability. The conceptual framework of state machines were-adopted in certain parts of industry and also the state diagram provides a clear picture of control functionality which makes troubleshooting easier. Hence this paper is an overview of developments considering practical issues in implementing new technologies which focus on working towards the goal to provide acceptable comfort conditions at lowest possible cost.

E. A building automation and control tool for remote and real time monitoring of energy consumption

Presenting building automation and control tools for remote and real time monitoring of energy consumption in the building sector is the main aim of this paper. Apart from the building profile analysis the tool also integrates scenarios which control minimization of energy consumption and rationalize the use of energy. This paper also addresses a "mechanical logic" problem of these systems, which makes the system to not work on remote control by the energy end-users and also focusing towards building automation and control systems which contribute to an improvement of building's energy performance. Further this paper introduces a dedicated graphical user interface with the benefits for monitoring the building's energy consumption and the combination of control scenarios by an automated system of sensors and meters. Finally, the advantages of using these control systems are listed which provide a road ahead for the same by applying in a real time scenario.

F. Integrating Building Automation Systems based on Web Services

This paper discusses the advantages and issues of integrating building automation systems (BAS) in intelligent buildings using networks like LAN and WAN. Referring two main international organizations, which promote the development of Web services in BAS domain such as Organization for the Advancement of Structured Information Standards (OSAIS) and American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE). These organizations announced "The purpose of Open Building technical committee (oBIX) is to develop a publicly available Web Services interface specification that can be used to obtain data in a simple and secure manner from HVAC, access control, utilities, and other building automation systems, and to provide data exchange between facility systems and enterprise applications" and "BACnet Web Services Initiative Goes to Public Review" respectively. Finally, these integration technologies, framework model and realization principles of BAS lead to develop a web-based BMS in a real intelligent building.

G. Review paper on energy efficiency technologies for Heating, Ventilation and Air Conditioning (HVAC)

This paper analyzes different approaches to improve the HVAC performance and reduce the overall energy consumption. Different strategies are analyzed and reviewed and the energy savings are noted. Further this paper addresses various strategies for energy saving in HVAC systems which were investigated for the system performance and their potentials to improve were discussed. It was found that several factors such as initial and capital cost, expected thermal comfort, climatic conditions, the application for overall attainable reduction in energy consumption and the availability of energy sources and enhancement of human comfort are dependent on the performance of HVAC systems in the building. Lastly all the approaches are compared to obtain the most effective solution based on energy conservation and thermal comfort.

H. A review of different strategies for HVAC energy saving

Different techniques to improve their energy efficiency and to reduce their environmental impact were implemented on HVAC systems along with different optimization and control strategies were also implemented in order to improve the energy consumption rates but these systems were very expensive and complex, hence these implementations were a bit not acceptable by the end users. Therefore, this paper focuses on reducing the cost and complexity by integrating the HVAC system which also makes the building energy efficient along with the desired comfort conditions. It follows a proven method of achieving energy efficiency in HVAC systems by designing systems that use novel configurations of existing system components. This paper also describes several factors such as; climatic condition, expected thermal comfort, initial and capital cost and the availability of energy sources are the prime factors considered to properly design and select an energy-efficient HVAC system.

I. Energy conservation building code tip sheet

This tip sheet by energy conservation, acts as a key source on the specifications of energy efficient HVAC systems. These include the proven technologies, design components and standard equipment for achieving optimal efficiency. Further the paper continues to describe the whole building approach in 8 steps, followed by explaining the parameters such as overview, types and efficiency tips for each sub component which includes; air conditioners, chillers, Air Handling Units (AHU), Building commissioning and indoor air quality. Finally, the concepts of Ozone depletion potential and Global warming potential and their direct relationship with refrigeration were discussed, also showing the various applications. The energy consumption criteria with respect to supply air or water is referred to the Energy Conservation Building Code (ECBC) norms which covers the requirements for HVAC systems including economizer, duct, pipe insulation, control optimization and system balancing.

J. How Does the Building Occupancy Influence the Energy Efficiency of HVAC Systems?

This paper discusses how the building occupancy influences the energy efficiency in HVAC systems. This is analyzed from three different perspectives: occupancy transitions, variations, and heterogeneity. The results show the significance of the three different perspectives and have also provided general ways of quantifying the influences of occupancy. The contributions by the perspectives include exploration of different occupancy-load, relationships for energy efficiency and new knowledge about the specific occupancy characteristics on effective HVAC loads. It acts as the starting point to decompose complicated interactions between HVAC, occupancy and thermal conditions and converts them into manageable control loops. This paper describes the importance of these investigations as it aims to model the influences of occupancy on energy efficiency irrespective of the building system types.

K. A novel simulation-based framework for sensor error impact analysis in smart building systems: A case study for a demand-controlled ventilation system

Xing Lua, Zheng O'Neilla, Yanfei Liab, Fuxin Niu in their paper have introduced a simulation-based technique to conduct a comprehensive sensor error impact analysis in building systems, which gives a stochastic sensor prioritization through a sensitivity analysis and a deterministic sensor error quantification. A case study of a sensor-rich CO2-based demand-controlled ventilation system is studied using a whole building simulation program, Energy-Plus, to demonstrate the viability of the methodology as a proof-of-the-concept. The Monte Carlo method is used for sensor error impact prioritization. The results show that ventilation performance is influenced mostly by the accuracy of AHU outdoor airflow sensors and that the zone CO2 sensor accuracy has more influence on the ventilation performance compared with the zone airflow sensor accuracy. The current implementation might be subject to limitations and uncertainties from multiple sources.

L. Novel demand-controlled optimization of constant-air-volume mechanical ventilation for indoor air quality, durability and energy saving

Sheng Zhang, Zhengtao Ai, Zhang Lin in their paper have proposed a novel on DCV for constant-air-volume mechanical ventilation. The proposed DCV operates the constant-air volume mechanical ventilation continuously and intermittently at full-load/quasi-full-load and partial-load conditions to create highly efficient. A genetic algorithm-based optimization is developed to determine the upper and lower concentration limits to maximize energy efficiency while satisfying the demand in indoor air quality and avoiding excessively frequent on-off operations. This method helps to improve the energy efficiency by 88% while meeting the demand of indoor air quality and durability.

M. Automatic HVAC control with real-time occupancy recognition and simulation-guided model predictive control in low-cost embedded system

Muhammad Aftab, Chien Chen, Chi-Kin Chau, Talal Rahwan in their paper the designing and implementation of an HVAC control system in a low-cost for occupancy-prediction and using Raspberry Pi 3 a powerful embedded system is used to practically prove the real-time recognition of occupancy by using machine-learning techniques and video-processing. Some of the ML techniques are used for prediction of dynamic analysis and also occupancy patterns. Thus the HVAC controls are guided by model predictive controls and real-time building thermal response simulations. These systems were evaluated in a mosque which was a good example of large public indoor space occupancy. Their results using practical simulations showed 90% of accuracy in recognition and 85% of accuracy in occupancy prediction. These real time simulations were done using a online open source software called Energy-Plus, which is able to achieve more than 30% energy savings and also maintaining the acceptable range of comfort level within the space.

N. Energy performance assessment of HVAC commissioning using long-term monitoring data: A case study of the newly built office building in South Korea

Dong-Bae Kim, Daeung Danny Kim, Taeyeon Kim in their paper have identified variables of the HVAC commissioning process through the help of analysis of energy efficiency of the HVAC system in a newly constructed office building. The energy demands for the case building are simulated by using data collected by BAS, BEMS and IPMVP Option D was used to calibrate conditions of the energy simulation. The results showed a decrease in 2 to 6% of total energy as per the occupancy rates and payback period which is used for development of HVAC commissioning for commercial buildings in the Korea.

O. Energy-saving building system integration with a smart and low-cost sensing/control network for sustainable and healthy living environments: Demonstration case study

KwangHoon Han and Jensen Zhang in their paper have looked at energy savings through a smart integration of HVAC with the use of a smart sensing network, embedded PIR/CO2 sensors and environmental system modelling while ensuring satisfactory thermal comfort and indoor air quality. A typical office building with multiple zones was utilized as a testbed. Two types of demonstration tests were performed under similar occupancy patterns and weather conditions; a) Baseline Test (3-day) with a normal building-operation following ASHRAE 62.1-2016 requirements, and b) Case Study (3-day) with a smart network-based demand control. The results showed energy savings up to 45% of fan electricity and 36.5% of room cooling/heating energy.

P. Enhancing environmental and energy monitoring of residential buildings through IoT

Vladimir Tanasiev, George Cristian Patru, Daniel Rosner, Gabriela Sava, Horia Necula, Adrian Bade in their paper have explored a solution with the application of IoT, in controlling and monitoring the HVAC system environment, comfort parameters and electrical network in a real building. The architecture proposed in this paper uses a protocol and Lora sensors for monitoring the building. Software integration approach has been used to integrate wired and wireless sensors. The communication between the cloud computing node, edge device and PLC is based on the IoT based protocol, which powers the devices. The system was monitoring and tested in a research laboratory which showed flexible results with the additional features of debugging, updating a specific module and optimizing solution for its normal monitoring of other parameters. Thus the proposed solution was identified by the main consumers which signaled through graphical form of data. Finally resulted in overall reduction of electrical and thermal power usage, it also reduces the greenhouse gas emissions making it very environment friendly.

Q. How much HVAC energy could be saved from the occupant-centric smart home thermostat: A nationwide simulation-study

Zhihong Pang, Yan Chen b, Jian Zhang , Zheng O'Neill, Hwakong Cheng, Bing Dong in their paper have conducted a comprehensive study and also the systematic analysis to determine the energy savings potential using a smart thermostat which is of occupant-centric and uses a large-scale nationwide simulation infrastructure. In order to save energy consumption in a home the occupancy sensing and also maintaining occupant's thermal comfort were used. Thus a single family model of building which was developed by the U.S. Department of Energy became a residential prototype and served its purpose of use. The simulated results showed 5 major impacts, that is; (1) By switching to 40% energy efficient heat pump on an average, in the place of gas furnace which acted as the heating source; (2) By adapting a method to save energy and also maintaining the occupant's thermal comfort by adjusting the setpoint of temperature during the unoccupied period; (3) By adapting a method to save energy and also maintaining the occupant's thermal comfort by adjusting the setpoint of temperature during the occupied periods; (4) Installation of smart recovery feature using the smart home thermostat's which decreases the HVAC energy savings ratio by 3%, also a comfortable temperature range of 30 min faster on average can also be seen, and the system also relieved occupant thermal discomfort; (5) Finally the 2°C of bringing an additional setback during occupied period could save about 20%; and in some extreme cases it was observed to be 40% as well. Thus ensuring a comfortable indoor temperature is necessary by means of turning the heating or cooling temperature setpoint up or down was adviced.

R. *IoT Based Indoor Air Quality and Smart Energy Management for HVAC System*

S.Dhanalakshmia , M.Poongothaib , Kaner Sharmaa, in their paper have proposed a simple HVAC control system that automates the operation in real time by considering energy management policies and user preferences. It is built on an IoT (Internet of Things) framework, where appliances in a laboratory are automated with suitable sensors and thermal parameters are obtained from sensors and user feedback information is collected for real-time processing in the cloud. Blynk Application Programming Interface (API) to monitor the real time data, to obtain user feedback and to adjust the temperature settings. The results show that Energy savings of 0.9 kWhr is achieved by this method.

S. Model predictive HVAC load control in buildings using real-time electricity pricing

Mesut Avci, Murat Erkoc, Amir Rahmani, Shihab Asfour in their paper have proposed a practical cost and energy efficient model predictive control (MPC) strategy for HVAC load control under dynamic real-time electricity pricing. The proposed model assigns reference temperatures to price ranges based on the consumer's discomfort tolerance index and accordingly generates efficient signal actions for each time period for the AC unit. The study reveals that the Model Predictive Control strategy can reduce the overall energy consumption and also increase the cost savings for the consumer on long term basis.

T. Smart ventilation energy and indoor air quality performance in residential buildings: A review

Gaëlle Guyot, Max H. Shermanc, Iain S. Walker in their paper have provided a literature review on smart ventilation used in residential buildings, based on energy and indoor air quality performance. The meta-analysis in this review includes 38 studies of various smart ventilation systems with control based on CO2, humidity, combined CO2 and total volatile organic compounds (TVOC), occupancy or outdoor temperature. Demand controlled ventilation based on CO2 or humidity improves indoor air quality using smart ventilation strategies. This study shows that, while energy savings up to 60% can be obtained by this, in some cases it also includes an overconsumption of about 26%.

U. Energy efficiency in HVAC system: case study of a hospital building comparing predicted and actual performance and showing improvements through performance monitoring

This paper presents a 350-bed multi-specialty hospital building which is located in Pune, this is a case study in warm humid climate focusing on the HVAC system performance by means of simulation by using impact analysis, and post occupancy measured data of few measures identified during the monitoring. This study talks about the Energy performance index (EPI) of two buildings that is commercial building and residential building in which commercial is much higher when compared with residential ones which also has a greater potential to save energy in terms of area measured in per unit. Further this paper describes, the EEM's in methodology adopted in the building in order to obtain the best design from results of the building energy simulation and HVAC system performance monitoring with specific measures for the system also focusing towards identification of available future energy saving opportunities. Hence aims to spread the knowledge to adopt energy efficiency measures.

V. Commercial Building Energy Efficiency Retrofit – a case study

This case study is about the building which had its HVAC system life at end of its operational life, difficulty in maintaining and expensive to maintain the occupant comfort using an existing HVAC system. The main objective is to have the installation of improved systems monitoring through a modern building management system (BMS), resulting in an annual cost savings in energy. In addition to savings in energy, an improvement in occupant comfort using plant reliability has increased together due to better controls and enhanced zoning arrangements. The National Strategy on Energy Efficiency proposed a ten-year strategy that aims to drive energy efficiency of HVAC systems based on long term improvements which was named as Heating, Ventilation and Air-Conditioning High Efficiency Systems Strategy and this strategy consists of a number of measures that are complementary which includes three broad initiatives by people, systems and practices.

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W. Case studies on HVAC system performance using a whole building simulation based real-time energy evaluation approach with BEMs

The real-time simulation system is applied to two existing buildings as case studies are evaluated by comparing the building energy monitoring data with real-time simulation results. A whole building energy simulation is used to evaluate building energy performance over the building operation stages which provide the real time data for simulation. The objective of this study is to demonstrate a model for the energy performance system integrated with BEMS in existing buildings. The paper also tries to identify the potential framework of the suggested system as a continuous commissioning tool in a boiler and HVAC system. This paper provides an insight that requires the evaluation criteria from the difference between measured and simulated data that can determine the abnormal operation or errors of building systems.

X. The different innovations developed over time in the field of HVAC systems

The Stationary Engineer working 24-Hour — The electric motor is operated by most of the components which heats, cools and ventilates an electric motor. In the year 1900, refrigeration compressors and fans were driven by heat engines and were steam operated, some were also powered using gasoline or oil. Some of the major disadvantages were that the construction needed skilled workers, the systems were extremely noisy, often dirty, and occupied a very large area. 1880–1910 saw the development of alternating current systems which revolutionized the HVAC&R industry by providing a simple and low cost solution to operate equipments. "Split-phase" induction motors were introduced and electric motors were modified by decreasing the weight and relative cost which improved the efficiency.

Cease Firing by Hand!—Automatic Heating: Earlier, before 1920s, most of the homes used central systems heated with boilers. They would go to a basement and get coal from a "coal bin,". During the World War I, the problem of coal shortage and to conserve energy the government initiatives gave a push to development automatic system in the United States. The first mechanically fed coal and removed ash from a furnace was an electric motor which was powered by coal stoker and was controlled by thermostat. The subsequent shortages of coal and war time restrictions stimulated the use of gas and oil which were the substitute energy sources for heating with the functionality of clock-operated, night setback thermostat and which is also a fuel-saving device.

Freedom from the Shackles of Ice — The Mechanical Refrigerator: In the year 1999, a study was conducted to understand which appliance was the most required and the findings revealed that it was the refrigerator. Previously, refrigerators used blocks of ice which was delivered door to door by an "ice man". This challenge was solved by introducing the new refrigerator designs. These closed-crankcase reciprocating compressors, refrigeration engineers introduced eccentric shaft, replacing open-frame crosshead and allowing smaller size and high operating speeds. The result was a very reliable machine which was energy efficient and which also turned out to be affordable.

Window Air Conditioner: It was the first successfully introduced room cooler, in 1929 which used sulphur dioxide with a bulky split-system as a refrigerant. During 1930s, the companies started to combine heating and cooling technologies for central home air-conditioning. This article explored how technology was invented, used or improved and how it works to keep us warm and cool in all seasons.

Y. Case study of an energy efficient commercial building: validating design intent and energy simulation results with monitored performance data

Prashant Bhanware, Pierre Jaboyedoff, Saswati Chetia, Sameer Maithel and Bharath Reddy in their paper have presented a case study focusing on energy efficiency in composite climate at Jaipur, in a day-use public office building. The paper discusses about the Energy efficiency measures (EEMs) being adopted for a building, including the external walls & roof, window-to-wall ratio optimization, glazing efficiently, high efficiency water chiller, rooftop solar photovoltaic system and T5 & LED lighting systems. The building was monitored during different seasons such as summer and winter and also analyzing the monthly energy bills for about a year. Thus using an energy simulation model which was calibrated for various seasons gave the results showing 53% in electricity consumption for HVAC annually, in which 31% was of electricity and office equipment and the remaining 6% by artificial lighting. These results were also checked for compliance with ECBC norms.

Z. The Role of Small Commercial Buildings in Achieving Energy Efficiency: Case Study Results

Commercial buildings consume most of the energy. Here we developed a Small Commercial 2030 District Program and Toolkit. This toolkit helps small commercial buildings participate in Architecture 2030 Districts has proven successful at reducing energy and CO2 consumption, predominantly in large commercial buildings in the city. This Paper reports the end uses impacted from the retrofits and explores correlations with retrofit measures implemented, climate zone, end uses impacted, building type, and energy savings. At the time of this publication, almost 20% energy savings were achieved with a single multi-family residential building. The data was collected in the 2030 District website and executed.

AA. *Existing buildings and the HVAC systems: incident of some innovative surface finishes on the requirements of energy*

Saving energy and reducing the related CO2 emissions are two very important measures. This paper analyses the incidence of innovative surface finishes on the cooling and heating energy demand of the previously existing buildings. These are easy and low-cost measures which help in saving small living spaces and the design characteristics of the buildings. An analysis was conducted for more than 10 cities in Europe with the help a of dynamic energy simulation software. The minimum energy required to run HVAC systems was calculated on a seasonal and annual basis and the energy savings was also noted.

BB. Reinforcement learning for whole-building HVAC control and demand response

In this paper a novel reinforcement learning (RL) architecture is proposed for the control of heating, ventilation and air conditioning (HVAC) systems and for efficient scheduling in a commercial building to obtain the demand response (DR) potentials while harnessing. These advanced automated B**MS** can be achieved by installing the smart autonomous reinforcement learning agent and by implementing holistic framework which gives best results by designing a RL controller which works efficiently for a whole-building model with the ability of learning to optimize with the help of feedback system and hence controling the HVAC system to improve thermal comfort levels and the energy efficiency in order to achieve demand response goals. Thus finally the simulation results are shown by applying the reinforcement learning for HVAC operations results in weekly maximum energy reduction can be achieved by employing a DR- RL controller during average power increases or reductions up-to 50% is achieved in demand response periods,.

CC. Building automation and control systems: A case study to evaluate the energy and environmental performances of a lighting control system in offices

Building automation and control systems (BACs) allow plants in buildings to be controlled and managed, thus this will increase the user's comfort and reduce the maintenance costs. The use control systems for managing lighting systems and reducing energy consumption, due to the use of integration strategies between daylight and electric lighting and strategies based on the occupancy of spaces. The results of an experimental case study of ten offices in Torino (Italy), a custom-design building automation and control system has designed to control both air conditioning system and lighting plants, the annual energy consumption was evaluated by applying the method by estimating the energy savings that by adopting the described lighting control system.

DD. Knowledge-based Automation for Energy Conservation and Indoor Air Quality Control in HVAC Processes

The HVAC tight building envelope creates low ventilation problems, which cause poor indoor air quality (IAQ). The Intelligent Operation Support System (lOSS) is built for HVAC processes consisting expert systems for conflict reasoning, operation planning, comfort setting, and different functions for several purposes. The Conflict reasoning gives the resolution for IAQ control and energy conservation in HVAC processes. A distributed intelligent system framework is used to integrate the existing systems, IOSS provides a real-time integrated planning operation method and used to train operators in HVAC systems to get better results. The IAQ operation mode was recommended when indoor CO2 concentration goes above certain limit and only then to use, outdoor air intake would increase. Switching to the energy-saving operation mode was then suggested to be used if indoor CO2 concentration was under specified limit. This mode specially was designed to utilize more fresh air and its energy for best results.

III. METHODOLOGY

This paper focuses on optimizing lighting and HVAC systems influencing the automation in industries whereas the other two approaches of building management systems as mentioned in the introduction, are directly taken from existing online sources. The standard references are taken by organizations such as ISO (International Organization for Standardization), ASHRAE (American Society for Heating, Refrigeration and Air-conditioning Engineers) and ISHRAE (Indian Society of Heating, Refrigeration and Air-conditioning Engineers). The basic method to obtain the energy efficiency in buildings vary between the organizations, ASHRAE follows its established 3 audit levels specially for commercial buildings:

1. ASHRAE Level 1 **-** This level defines a “walk-through” audit which is a detailed review of the historical data along with a short review onsite, the assessment of energy systems, assessment of the building and finally the identification and preliminary analysis of opportunities to energy efficiency.
2. ASHRAE Level 2 **-** This is the second step and also an important level that includes visit to the site along with the measurements and data logging for comprehensive, a complete thorough assessment of energy and the financial analysis of the energy efficiency opportunities.
3. ASHRAE Level 3 – This is the final level which includes a complex auditing comprising of detailed analysis of energy savings, baselines and financial analysis to maintain the capital-intensive measures.

These levels are successful only by various measurement instruments in order to obtain the energy efficiency of the buildings. The examples of equipment for detailed audit measurement includes 4 broad categories such as; **Electric Power -** Recording ammeters and voltmeters, Watt hour meters, Power factor meters, Demand meters, Data logger system, etc. **Thermal Measurements -** Recording thermograms, IR scanners, thermometers, Heat flux meters, Digital thermometers, Combustion gas analyser, Psychrometers, flue gas analyser, etc. **Flow Measurements** – Manometers, pressure gages, Airflow gauges, velocity gauges, Water flow meters, etc. **Mechanical Measurements** – LVDTs, Load cells, velocity transducers, Tachometers, accelerometers, etc.

Based on the literature review, the HVAC systems mark 40 – 50% of its contribution towards energy efficiency which comprises the efficiencies by its system components.

Hence the total energy use by the HVAC system can be estimated by the sum of energy use by each component which is given by,

HVAC Energy Use = Heating Energy use + Cooling Energy use + Air Distribution Energy use + Cold storage Transfer + Other HVAC Energy use
Units: kWh or Joules

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The Energy Efficiency, Coefficient of performance (COP), Energy Efficiency ratio (EER) and Seasonal Energy Efficiency ratio (SEER) for the components specifically can be calculated using the formula as follows,

$$\textbf{Energy Efficiency} = \frac{Useful\ Energy\ output}{Energy\ input} \times \%$$

$$\textbf{COP} = \frac{power\ output}{power\ input}$$

$$\textbf{EER} = \frac{output\ energy\ (BTU)}{input\ energy\ (Wh)}$$

$$\textbf{SEER} = \frac{output\ energy\ over\ a\ season\ (BTU)}{input\ energy\ over\ a\ season\ (Wh)}$$

***Case 1**: Mercedes Benz Research and development*

MBRDI uses a vertical solution which unifies the UI, hardware, software, data analytics and services for providing integrated HVAC, IBMS & Lighting Control & Automation capabilities.

Smart sensors collect real-time data for VOCs, CO2, movement, humidity, temperature, LUX levels, sound levels and the occupancy levels for each zone.

A Dynamic Airflow Balancing System and Dynamic Chilled Water System were installed which ensures both comfort and energy efficiency.

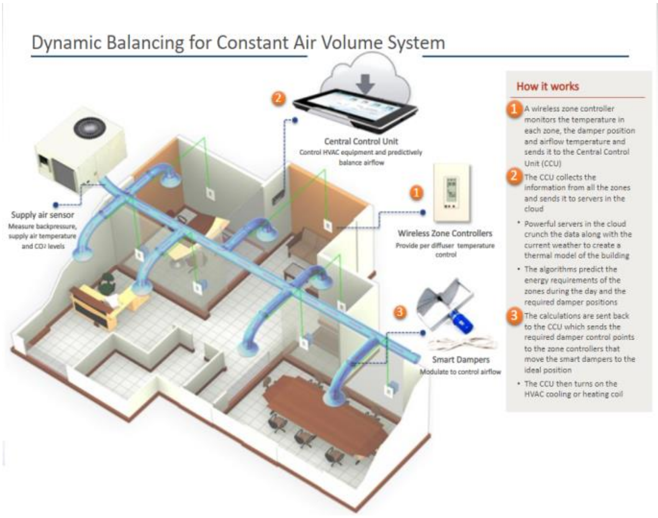


Fig 3:- Dynamic airflow balancing system

The system proactively controls the chilled water flow rate, moderates the VFDs for fan motors, controls the AHUs and modulates the Smart Dampers installed across the site on the thermal, airflow and humidity requirements in each zone. All the HVAC units in facility work together to reduce energy consumption and provide even temperatures throughout the utility. This system is also connected to the VRFs at the site. Smart Nodes are used to communicate with the VRF indoor unit and to control it based on setpoint temperatures, occupant preferences and schedules.

The system uses heatmaps, occupancy maps, trends, analysis and granular reporting. This automated solution is capable of automatically controlling, managing and monitoring the HVAC system. It also enables the FM power to control their buildings at any place and time.

This automated solution not only helps MBRDI save 25% on Lighting energy & HVAC but also improves occupant experience while enhancing operational efficiencies.

***Case 2:** Flipkart*

Flipkart deployed a Dynamic Airflow Balancing solution in their facility. installed Three Centralised Control Units (CCUs), 32 Smart Dampers and 20 Wireless Room Modules (WRMs) help to monitor, manage and control the HVAC system, which helps Flipkart achieve good sustainability and energy savings. The Facilisight app helps the Flipkart facility manager receive the required insights for optimum operation and preventive maintenance. The sensors take a thermal snapshot every minute to build a vast empirical model that informs the smart algorithms in the cloud. These smart algorithms wirelessly transmit data back to the VAVs or smart dampers, proactively adjusting throughout the day to regulate temperatures. All these wireless devices are controlled by Central Control Units.

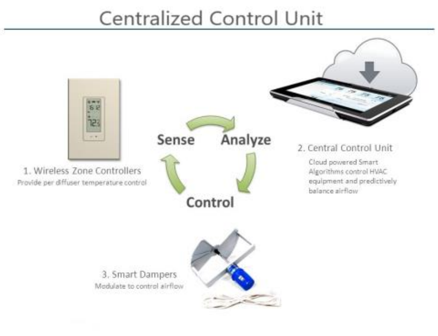


Fig 4:- Centralized control unit

The facility manager now has greater insight and control over the facility and is able to monitor energy usage in real-time.
The automated solution has delivered up-to 32% energy savings on HVAC at the Flipkart facility by optimising the compressor run time.

IV. RESULTS AND DISCUSSION

Installation and setup took two technicians five days to complete.

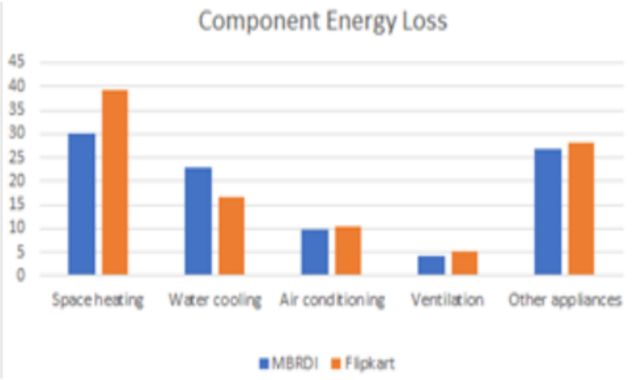


Fig 5:- Component Energy Loss

Energy Loss	MBRDI	Flipkart
Space heating	30.2	39.2
Water cooling	22.9	16.8
Air conditioning	9.8	10.3
Ventilation	4.2	5.1
Other appliances	26.7	28.2

Table 1:- Energy Loss in MBRDI and Flipkart

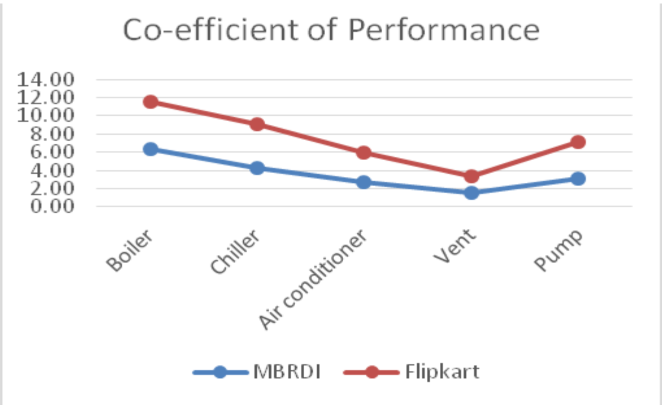


Figure 6:- Co-efficient of Performance

COP	MBRDI	Flipkart
Boiler	6.41	5.12
Chiller	4.20	4.90
Air conditioner	2.70	3.30
Vent	1.59	1.71
Pump	3.10	4.00

Table 2:- Co-efficient of Performance

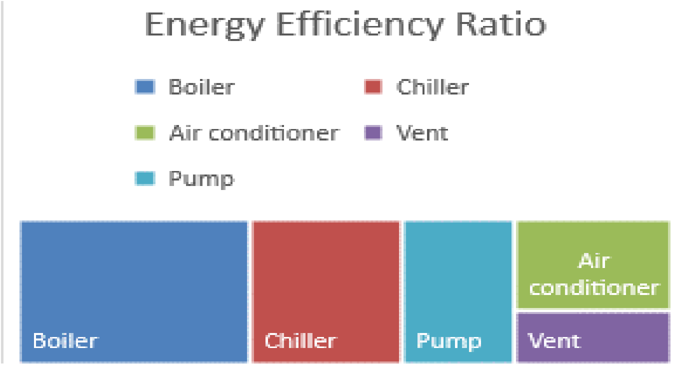


Figure 7:- Energy efficiency ratio

Energy efficiency ratio	MBRDI	Flipkart
Boiler	21.88	17.47
Chiller	14.33	16.72
Air conditioner	9.22	11.26
Vent	5.43	5.84
Pump	10.58	13.65

Table 3:- Energy efficiency ratio

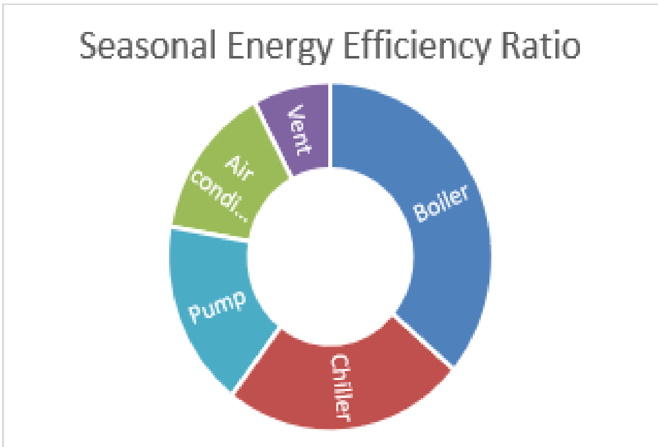


Figure 8:- Seasonal energy efficiency ratio

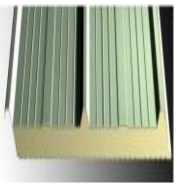
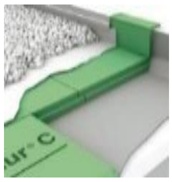
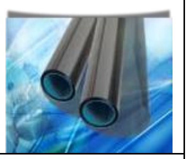
SEER	MBRDI	Flipkart
Boiler	25.00	20.10
Chiller	16.70	19.50
Air conditioner	10.01	13.12
Vent	5.35	5.81
Pump	12.02	17.90

Table 4:- Seasonal energy efficiency ratio

The above case studies prove that the energy efficiency of the Building systems increases with the installation of automated control systems for HVAC systems.

The use of self-learning AI techniques, radiant cooling, auto dynamic diagnosing and dynamic change overs in the system is suggested, to increase the energy efficiency and savings by leaps and bounds.

Thus, providing an insight to further research on the best available technologies, applications, minimum performance criteria or minimum requirements, International reference standards and also a visual examples present in this area and here are some examples of the same.

N.Ref	Best Available Technology (BAT)	Applications	Minimum Performance Criteria/ Minimum requirements	International Reference Standards	Visual Example
A.	**Improve the thermal performance of Building Envelope**				
A.1.	**Roofs and Walls**				
A.1.1.	**Metals Panels- insulated Polyurethane, Extruded polystyrene**	**Existing or new industrial buildings (example: air conditioned warehouses)**	Min criteria for roof: U< 0,4 W/m, 2 °C For walls: U<0, 5 W/m2	ASTM C518, ASHRAE 90.1	
A.1.2.	**Expanded polystyrene panes, glass wool ,spray polyurethene foam**	**Buildings with air conditioners: apartment buildings, offices, production plants, hotels hospitals**	Min criteria for roof: Roof : U< 0,4 W/m2 waterproof covering Walls : U<0, 5 W/m2	CE MARK, ASHRAE	
A.2.	**Windows**				
A.2.1.	**Glazed windows on both side and low SHGC glass**	**New or retrofit of all kinds of air- conditioned buildings; windows exposed to direct sunshine**	Global U factor $\leq$ 2 W/m 2°K Low E coating solar heat gain coefficient <0	CE Marking- EN ISO 10077-1, ASHRAE	
A.2.2.	**Window with heat resistant film**	**Air- conditioned buildings, windows exposed to direct sunshine**	Solar energy reflection>50%	ASHRAE	
A.2.3.	**External Shading devices: blinds, window covers, horizontal or vertical sun protectors on the façade**	**air- conditioned buildings; protection type depends on the sunshine exposure**	Direct sunshine must be avoided on more than 80 % of the facade in all seasons	ASHRAE	
B.	**Improve HVAC & Refrigeration system performance**				
B.1.	**Individual Air-conditioning system**				
B.1.1.	**Mono split air cooled with inverter cool G<12 Kw**	**For small air conditioned spaces (housing, offices, retail stores….)**	At least Energy Efficiency class : A++ or SEER > 6	Commission Regulation (EU) No 626/2011 ASHRAE	
B.2.	**Small and medium range air conditioning systems**				
B.2.1.	**Variable refrigerant flow systems**	**For buildings with 40 rooms - housing, offices, hotels**	EER $\geq$ 3.4 VSD	EU IPPC BAT EE, US DOEEN 814-2/3 (E 36-104-2/3), ASHRAE	

					
B.3.	**Large range air conditioning systems – chillers**				
B.3.1.	**Air cooled high efficiency chiller**	**private and public ac offices, hotels, hospitals**	Eurovent class A EER> 3,1 or Inverter ESEER >4,5 Hydrocarbon HFC refrigerants only		
B.3.2.	**Water cooled -high efficiency chillers**	**Large public and private ac office, hotels, hospitals**	Eurovent class A EER>5,1 Hydrocarbon HFC refrigerants only	Eurovent, ASHRAE	
B.3.3.	**Absorption and adsorption refrigeration unit**	**Industrial plants, hotels, hospitals equipped with solar heating panels**	Only when free solar energy is available		
B.4.	**Large range air conditioning systems - cooling towers**				
B.4.1.	**Dry cooling tower with high efficiency fans, VS and motors**				
B.4.2.	**Evaporative cooling tower , IE2 fan motors and VSD**	**Large AC installations with water cooler, industrial plants, offices, buildings, hospitals**	At least IE2 class efficiency motor , VSD	CTI Standards, ASHRAE	
B.4.3.	**Evaporative cooling tower with hybrid condenser, IE2 fan motors**				
C.	**General process equipment**				
C.1.	**Fan**				
C.1.1.	**High efficiency fan**	**IE5 class efficiency motor**		ASHRAE	
C.2.	Pump				
C.2.1.	**High efficiency pump**	**Applicable to pumps for ice water networks, cooling loops and pumps**	IE 5 class efficiency motor + VSD	ASHRAE	
C.3.	**Heat pump**				
C.3.1.	**heat pump with high efficiency**	**production of medium-temperature hot water and production of domestic hot**	COP ≥ 5.10 5 (water to water type)	European Heat Pump	

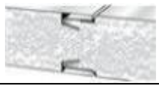
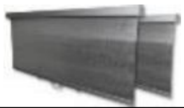
		water in hotels	COP ≥ 3.8 (air to water type)	Association, ASHRAE	
C.4.	**Sensors and metering**				
C.4.1.	**Pressure, Temperature, Humidity, Mass flow rate, power, lumens**	**Applicable to all industrial processes and tertiary secto**		CE marked ; Compatibility to EN 15500, ASHRAE	 
D.	**Specific Process equipment**				
D.1.	**Cool rooms, refrigerated showcases and display cabinets**				
D.1.1.	**High efficiency cool rooms, refrigerated showcases and display cabinets**	**Include reinforced walls and insulate roof, high efficiency compressors and fans ,high efficiency LED lighting, VSD drive.**		ASHRAE	
D.1.2.	**Reinforced wall and roof insulation**	**For cold rooms**		ASHRAE	
D.1.3.	**Blinds used at night**	**Food displays**		ASHRAE	
E	**Renewable Energy**				
E.3.	**Micro hydroelectricity**				
E.3.1.	**Hydroelectric turbine**		**Efficiency > 80%**	ASHRAE	
E.3.2.	**Generator, Alternator**		**Efficiency > 85%**	IEC 60034 IEC 1116 (Electromechanical equipment Guide for small installations)	
F.	**Improve performance of steam production and steam network**				
F.1.	**Boilers**				
F.1.1.	**steam boilers with high efficiency**	**For tertiary and industrial us - hotel laundery**	**Net thermal efficiency ≥ 92%**	EU IPPC BAT EE ; Council Directive 92/42/EEC; ASHRAE	
F.1.2.	**Economiser (Non-condensing)**	**for improving the efficiency of industrial boiler rooms**	**Efficiency by up to 4%.**		
F.1.3.	**Condensate recovery system**	**For manufacturing units which use steam in heat exchangers – food Processing**	**Recovery efficiency 5 to 10 % of fuel energy consumption**		

Table 5:- Best Available Technology

V. CONCLUSION

This paper presents analysis of two case studies based on automation in industrial HVAC systems and covers:

a) Energy efficiency measures adopted in the existing systems.
b) Results of building energy simulation including COP, EER and SEER.
c) Methodology and results of performance monitored for a period of a year.

Energy efficiency measures for these case studies include installation of Dynamic Airflow balancing, Dynamic chilled water balancing, advanced lighting solution, outside air optimization and Smart sensors to collect real time data for centralized control monitoring.

Thus this paper shows that installation of automated HVAC system technologies results in better energy efficiency. Further this paper also discusses existing best improvement opportunities in HVAC systems to motivate researchers and professionals to adopt energy efficiency measures.

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