STUDY OF EFFECTIVENESS OF CONTEMPORARY STANDARD VAV HVAC SYSTEM OVER CONVENTIONAL MULTI ZONE AIR HANDLER HVAC SYSTEM IN AN 8 STOREY FINANCIAL INSTITUTIONAL BUILDING AT AKOLA, MAHARASHTRA, INDIA THROUGH ENERGY MODEL SIMULATION SOFTWARE

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ABSTRACT

The world today is a complex system advancing through time trying to work its way around the First Principle of Thermodynamics 'Energy can neither be created nor be destroyed'. With the world population increasing at an unprecedented rate and an ever-increasing energy demand, it is of vital importance to make use of the energy available to us in the most effective way possible. Rapid advancements in technology since the mid 20th century have had a major impact on elevating the standard of living of the world populace. Technologies and services thought of as exotic and out of reach of common people are now becoming widespread and common. One such technology is the Heating Ventilation and Air Conditioning (HVAC) system. The proportion of electrical energy consumed by these systems with respect to the total electrical energy generated is a sizeable amount. Optimizing the energy consumption of HVAC systems is thus an important criterion when discussing energy efficiency. This paper explores the difference in the efficiency of a contemporary standard VAV HVAC system and a conventional multi-zone air handler HVAC system applied to a hypothetical financial institutional building situated at Akola, Maharashtra, India.

KEYWORDS: Energy Efficiency, Optimization, HVAC ASJC Codes: 2102, 2611

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INTRODUCTION TO HVAC SYSTEMS

HVAC stands for Heating Ventilation and Air Conditioning. HVAC systems are of immense utility in controlling and maintaining the thermal conditions in the spaces they are deployed. HVAC systems are responsible for the temperature, humidity, thermal comfort and indoor air quality of the designated space. Any standard HVAC system has 3 main components namely heating, ventilation, and air conditioning.

The heating component in an HVAC system provides temperature control and maintenance by heating the air circulated in the space as required. On a broad scale, heating systems are classified into two types. The central heating system used to provide heating for an entire building or a collection of zones. This system uses a furnace, a heat pump, or a boiler to heat a fluid which is then circulated using a separate mechanism throughout the zone to provide heating and warmth. On the other hand, a space heater is used to heat a relatively small space such as a room.

Ventilation is the component of any HVAC system which ensures proper circulation and replacement of air between the indoor and outdoor spaces. The ventilation system is used to filter out odor, smoke, airborne bacteria, and dust from the circulating air. It's another essential function is to replenish oxygen in the air and remove excess carbon dioxide. Ventilation systems are of two types, mechanical ventilation (uses mechanical aids such as fans) and natural ventilation. Ventilation systems are primarily responsible for ensuring acceptable air quality.

The air conditioning ensures cooling and humidity control in a building. Cooling is carried out by the extraction of heat from the circulating fluid. This heat extraction is carried out in line with the refrigeration cycle by performing the processes of condensation, expansion, evaporation, and compression in the written order. The air circulating within the system is periodically refreshed by mixing outdoor air in order to maintain freshness and hygiene standards. This process is aided by the ventilation system. A major pre-requisite of any space to be air-conditioned is to be well sealed for the system to maintain indoor thermal conditions with relative ease and efficiency.

STANDARD VAV HVAC SYSTEM

Standard VAV HVAC system is the abbreviation for standard variable air volume heating ventilation and air conditioning system.

In a conventional multi-zone air handler HVAC system, air follows the following path:

Figure 1: Air Path Diagram in a Conventional Multi- Zone Air Handler HVAC System.

It is clear from the above diagram that, in the entire system, there is a lack of control over the volume of air circulating. For example, The above system is deployed in a building which caters 200 people every day during the working hours and the system performs efficiently but when if due to some circumstances the occupancy is reduced by 50%, the system becomes inefficient as there is no control over the volume flow rate of air and thus has to either be replaced or upgraded.

On the other hand, in a standard VAV HVAC system, a device called 'VAV Box' is installed in addition to the multi-zone air handler HVAC system.

The air follows the following path in a standard VAV HVAC system:

Figure 2: Air Path Diagram in a Standard VAV HVAC System.

This device consists of an air inlet with an airflow rate measurement sensor, a control panel, an actuator, a damper, an air reheater, and an outlet.

Figure 3: A VAV Box. (Reference: <https://medium.com/@clareruskint/how-vav-box-works-dafba378fcb1>).

ADVANTAGES OF USING A VAV HVAC BOX

Conditioned air (typically at 13 °C/ 55.4 °F) enters the VAV box via the inlet. The airflow rate is measured by the sensor attached to the inlet. A thermostat installed in the zone being serviced by the VAV box is used to control the amount of air entering the box via the damper. The damper controlling the amount of air entering the box is controlled by the actuator which in turn is controlled by the control panel linked to the thermostat. The air reheater is used to heat the air to the desired temperature and then the air enters the HVAC zone. The pressure difference between the inlet and the outlet is calculated by the control panel and is used to regulate the airflow to a finer degree of precision. Thus, a VAV box controls the HVAC conditions in the given zone, and by allowing variations in supply when variations in demand arise; it consumes electricity in a highly efficient manner leading to savings on energy consumption. In typical cases, a damper never stems the airflow completely but reduces it to a large extent. In cases when the pressure difference in the ducts and in the VAV system varies, this leads to over-pressurization of the ducts. To handle such situations, a pressure sensor is installed prior to the box and another pressure sensor is installed in the air handling unit. This allows the unit to send specific inputs to the fans running them as per demand in turn reducing energy consumption as well.

Hence, over the span of its operational life, a contemporary standard VAV HVAC system not only reduces energy consumption but also reduces wear and tear in its components, cuts maintenance expenditure by a substantial margin, and increases the operational life of the system which in turn decreases operating costs and provides a relatively environment-friendly solution to HVAC problems faced by buildings as compared to a conventional multi-zone air handler HVAC system.

MODELLING METHODOLOGY

In order to model the selected building and simulate its electrical energy consumption, the software eQUEST (Quick Energy Simulation Tool) is used. eQUEST is an open source software allowing the user to model a building and simulate and optimize its energy consumption. The building is designed as a baseline model and the eQUEST window showing the completed building's 3-D block model is shown below.

Figure 4: 3-D Block Model of the Selected Building.

The building is modelled using eQUEST's design development wizard (DD Wizard).

The building footprint and orientation are shown in design development wizard's 'Building Footprint' screen as shown below.

Figure 5: Building Footprint Input Window.

Once the building footprint and site details are set, the construction details of the building which include details of above grade walls, below grade walls, roof construction details etc. are taken into account. In order to best understand the differences between the two types of HVAC systems, the building envelope is kept as a constant i.e. having the same features allowing the simulation results to highlight the differences in energy consumption of the two HVAC systems selected.

The building construction details as used in modelling are shown in the 'Building Envelope Constructions'. The input window for building envelope construction details is shown below.

Figure 6: Building Envelope Constructions Input Window.

The building has a configuration of basement + ground + eight storeys. The activity areas within the structure are customized using the 'Activity Areas Allocation' window in the eQUEST's design development wizard.

The activity areas allocation window for the selected building is shown below.

Figure 7: Activity Areas Allocation Input Window.

In order to reduce and optimize energy consumption (electrical energy in this case), eQUEST's Energy Efficiency Measurement Wizard (EEM Wizard) is used. First, the baseline model is constructed in the design development wizard as shown above. Then, the energy efficiency wizard allows the user to change a specific input type; for example, the orientation of the building, the building insulation, window/door overhangs etc. In this case, the type of HVAC system is used as the energy efficiency measure and the model is simultaneously simulated for its electrical energy consumption.

The energy efficiency wizard enables the user to select the specific design input. The conventional multi-zone air handler HVAC system is selected in the first model.

The energy efficiency measure wizard screen used to select the type of HVAC system, the 'HVAC System Definition' window is shown below.

The screenshot shows the 'HVAC System Definition' window in eQUEST DD Wizard. The window title is 'eQUEST DD Wizard: Air-Side System Type -- HVAC System 1'. The 'System Type Name' is 'HVAC System 1'. The 'Cooling Source' is 'Chilled Water Coils' and the 'Heating Source' is 'No Heating'. The 'System Type' is 'Multizone Air Handler (cooling only)'. The 'System per Area' is 'System per Floor' and the 'Return Air Path' is 'Ducted'. The 'Component Name Prefix' is 'S1' and the 'Suffix' is empty. A note indicates that the prefix and suffix characters must be less than or equal to 4. There is a checkbox for 'Prevent duplicate model components' which is checked. Below this is a table for 'System Assignment to Thermal Zones*'. The table has two columns: 'Shell Component(s)' and 'Description of Assigned Zones'. The first row shows 'Bank 1' assigned to 'All Zones'. The second row shows '- undefined -'. A note at the bottom states: '* Assignments here are superseded by HVAC assignments made on the zone group screen (by shell)'. At the bottom of the window, there is a 'Wizard Screen' indicator showing '1 of 7', a 'Help' button, and navigation buttons for 'Previous Screen', 'Next Screen', and 'Return to Navigator'.

Figure 8: HVAC System Definition Input Window (Type of HVAC System Set to Multi-Zone Air Handler HVAC System).

After setting the type of HVAC system to multi-zone air handler system, a new energy efficiency measurement model is created in which the HVAC system is set to standard VAV HVAC system.

The HVAC system definition window for the standard VAV HVAC system is shown below.

The screenshot shows the 'HVAC System Definition' window in eQUEST DD Wizard. The window title is 'eQUEST DD Wizard: Air-Side System Type -- HVAC System 1'. The 'System Type Name' is 'HVAC System 1'. The 'Cooling Source' is 'Chilled Water Coils' and the 'Heating Source' is 'No Heating'. The 'System Type' is 'Standard VAV (no reheat)'. The 'System per Area' is 'System per Floor' and the 'Return Air Path' is 'Ducted'. The 'Component Name Prefix' is 'S1' and the 'Suffix' is empty. A note indicates that the prefix and suffix characters must be less than or equal to 4. There is a checkbox for 'Prevent duplicate model components' which is checked. Below this is a table for 'System Assignment to Thermal Zones*'. The table has two columns: 'Shell Component(s)' and 'Description of Assigned Zones'. The first row shows 'Bank 1' assigned to 'All Zones'. The second row shows '- undefined -'. A note at the bottom states: '* Assignments here are superseded by HVAC assignments made on the zone group screen (by shell)'. At the bottom of the window, there is a 'Wizard Screen' indicator showing '1 of 7', a 'Help' button, and navigation buttons for 'Previous Screen', 'Next Screen', and 'Return to Navigator'.

Figure 9: HVAC System Definition Input Window (Type of HVAC System Set to Standard VAV HVAC System).

In order to highlight the difference in the electrical energy consumption of the two HVAC system types, the other fineries in the HVAC system, mainly the HVAC system's operating schedule and operating temperature ranges are set at the same values.

The basic difference in the standard VAV HVAC system's and multi-zone air handler HVAC system's operational temperature ranges control menu is that a minimum value of variable air volume flow can be set as per one's wish in the standard VAV HVAC system window while the multi-zone air handler HVAC system's minimum variable air volume is set by default to 100%, cementing the fact that the former system lends a greater degree of control.

The window used to set operating temperatures in the eQUEST module is termed as 'HVAC Zones: Temperatures and Air Flows'.

Note the difference in variable air volume minimum flow in the two types of HVAC system shown below.

eQUEST DD Wizard: Air-Side System Type -- HVAC System 1

HVAC Zones: Temperatures and Air Flows

System(s): 1: Multizone Air Handler (cooling only)

Thermostats

Occupied (°F)		Unoccupied (°F)	
Cool	Heat	Cool	Heat
76.0	70.0	82.0	64.0

Thermostat Location: Within Zone

Design Temperatures and Air Flows

Cooling Design Temp: Indoor 75.0 °F, Supply 55.0 °F

Minimum Design Flow: 0.50 cfm/ft2

VAV Minimum Flow: Core 100.0 %, Perimeter 100.0 %

Wizard Screen 2 of 7

Help Previous Screen Next Screen Return to Navigator

Figure 10: HVAC Zones: Temperatures and Air Flows Input Window for Multi-Zone Air Handler HVAC System.

eQUEST DD Wizard: Air-Side System Type -- HVAC System 1

HVAC Zones: Temperatures and Air Flows

System(s): 1: Standard VAV (no reheat)

Thermostats

Occupied (°F)		Unoccupied (°F)	
Cool	Heat	Cool	Heat
76.0	70.0	82.0	64.0

Thermostat Location: Within Zone

Design Temperatures and Air Flows

Cooling Design Temp: Indoor 75.0 °F, Supply 55.0 °F

Minimum Design Flow: 0.50 cfm/ft2

VAV Minimum Flow: Core 40.0 %, Perimeter 30.0 %

Wizard Screen 2 of 7

Help Previous Screen Next Screen Return to Navigator

Figure 11: HVAC Zones: Temperatures and Air Flows Input Window for Standard VAV HVAC System.

The building's HVAC system operates within a given timeframe each day. The HVAC system's operating schedules are shown below. It is important to note that the operating time is equal in both the cases.

The HVAC system's operating schedule is input using 'HVAC System: Fan Schedules'.

The HVAC system fan schedule input window for the multi-zone air handler and standard VAV HVAC system are shown below.

eQUEST DD Wizard: Air-Side System Type -- HVAC System 1

HVAC System #1 Fan Schedules

HVAC System 1: Multizone Air Handler (cooling only) Cycle Fans at Night: No Fan Night Cycling

Operate fans 1 hours before open and 1 hours after close.

Entire Year
1/1-12/31

	On At	Off At
Mon:	6 am	8 pm
Tue:	6 am	8 pm
Wed:	6 am	8 pm
Thu:	6 am	8 pm
Fri:	6 am	8 pm
Sat:	8 am	5 pm
Sun:	Off	
Hol:	Off	

Wizard Screen 5 of 7

Figure 12: HVAC System Fan Schedule Input Window for Multi-Zone Air Handler HVAC System.

eQUEST DD Wizard: Air-Side System Type -- HVAC System 1

HVAC System #1 Fan Schedules

HVAC System 1: Standard VAV (no reheat) Cycle Fans at Night: No Fan Night Cycling

Operate fans 1 hours before open and 1 hours after close.

Entire Year
1/1-12/31

	On At	Off At
Mon:	6 am	8 pm
Tue:	6 am	8 pm
Wed:	6 am	8 pm
Thu:	6 am	8 pm
Fri:	6 am	8 pm
Sat:	8 am	5 pm
Sun:	Off	
Hol:	Off	

Wizard Screen 5 of 7

Figure 13: HVAC System Fan Schedule Input Window for Standard VAV HVAC System.

Thus the two energy efficiency models are created using eQUEST's design development wizard and energy efficiency measurement.

VERIFICATION OF THEORY USING ENERGY MODEL SIMULATION SOFTWARE AND DISCUSSION OF RESULTS

In order to verify the theory presented above, a hypothetical building is used. This building is situated in Akola, a town in the Indian state of Maharashtra. The structure consists of a basement cum parking garage (30,000 Sq.ft.) and a Ground+8 superstructure with each floor having an area of 30,000 Sq.ft.

The above building is modeled on eQUEST (Quick Energy Simulation Tool) and the model is simulated for its total electricity consumption considering two cases.

- Case 1: The building uses a conventional multi-zone air handler HVAC system.
- Case 2: The building uses a contemporary standard VAV HVAC system.

The simulations provide us with a graphical and tabular break-up of electricity consumption.

The results are as follows:

Figure 14: Electrical Energy Consumption Break-Up (Pertaining to each use Distributed Monthly and Total Consumption) for Multi-Zone Air Handler HVAC System.

Figure 15: Electrical Energy Consumption Break-Up (Pertaining to each use Distributed Monthly and Total Consumption) for Standard VAV HVAC System.

It is of vital importance to interpret the data depicted above. In the above two cases, a major difference in electricity consumption is observed due to the difference in electricity consumed by ventilation fans and space cooling, as electrical energy consumption of other aspects is fairly constant across both the cases. This verifies the fact that the substantial difference in electricity consumption in the above-considered cases is due to the difference in electricity consumption of a Multi-Zone Air Handler HVAC system as compared to a Standard VAV HVAC system.

CONCLUSIONS

The above study, based on a hypothetical financial institutional building at Akola, Maharashtra, India produced the following results:

- Case 1: The building uses a conventional multi-zone air handler HVAC system.

The electricity consumption of the building was found upon simulation to be 7674540 kWh annually.

- Case 2: The building uses a contemporary standard VAV HVAC system.

The electricity consumption of the building was found upon simulation to be 5745552 kWh annually.

This study establishes, on the grounds of data obtained from energy simulations of the chosen cases that a contemporary standard VAV HVAC system is 25.13% more efficient in terms of electricity consumption and hence operational cost with respect to conventional multi-zone air handler HVAC system.

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