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# Assessment of Building Performance by Energy Retrofits of Building Services

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***Abstract:*** *The colossal majority of existing buildings are impacting our environment in notable ways including an energy perspective. It is well inveterate that building energy use can account for up to 30 to 40%of the total greenhouse gas emissions which have been rising steadily since the 1950s [1,2].The built habitat is therefore a critical part of the climate change problem and solutions. Although the increased requirement for thermal comfort in buildings has increased the energy demand for various building services notably HVAC and lighting. Considering the fact that a majority of government buildings are old constructions and therefore large consumers of energy, the Ministry of Finance, Government of India, has issued guidelines for mandatory installation of energy efficient appliances in all Central Government buildings across India on 5th January, 2015 under the aegis of the National LED Programme.*

*This study considers the retrofitting potential of building services in existing buildings to achieve energy efficiency. Although there are a number of retrofit technologies promptly available, whereas methods of most cost-effective retrofit measures are still major technical challenges for particular projects. An overview of the publications and applications of the retrofit technologiesin existing buildings is also provided. The aim of this work is to provide building researchers and practitioners with a better understanding of assessment of building performance by energy retrofit through existing government building assessment to promote energy conservation and sustainability. Paper focuses on only building services to establish the feasibility of technologies and assemblies to improve the building energy performance and also to understand the decision making technique as best option for retrofitting of existing building by identifying various parameters.*

***Keywords:****Building Performance, Assessment, Energy, Retrofitting, Building Services, Delphi Technique*

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## I. Introduction

Whenever **Building performance**is discussed it is totally about impute of a building defining its overall function. It can be evaluated at different stages as pre-design, energyaudits, design, on-going performance and so on. The performance of building after construction process can be evaluated with two main categories quality (how appropriately the building fulfils its functions) andresourcesaving (how ample resource is needed to fulfil its functions).Building performance is importantly related to architecture,building services engineering, architectural engineeringandconstruction management. Notable building performance aspects are **energy efficiency**,thermal comfortand day lighting.Incessant through the last many years of energy market evolution has been the foremost interest from commercial building owners and energy managers in understanding the energy performance of a building. Energy performance of a building can be evaluated in two ways ,first being its baseline at which the building is originally performing where it is, and second being for the betterment of building performance by energy retrofit by different ways.

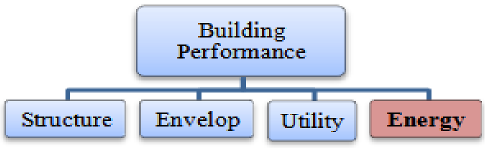


Figure 1 Specified areas for building performance assessment (by author)

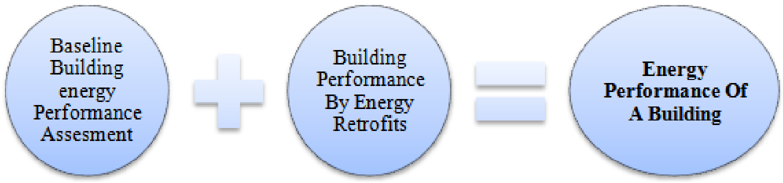


**Figure 1 Energy performance of a building (by author)**

Retrofitting itself includes evolving functional ability of any structure and when specifically energy retrofitting is discussed it's about evolving the energy efficiency of an existing building. But eventually, there are number of researches has already been done to carry out different energy efficiency to improve energy performance of existing building. Nowadays there are end number of retrofitting technologies introduced in market whereas the decision making regarding the use of technologies for particular type of project is still a big problematic subject to some constraints such as type of building, use of building ,total budget, age of building, type of building services installed etc. Costing should not always be the only beneficial criteria it includes related or non-related energy factors, such as technical, social, reliable, energy and environmental etc. Objective of this paper an overview of recent work and research in field of retrofitting as well as the case studies to identify the most needed retrofitted building services to make the existing building energy efficient.

## I. Review Of Literature

The problematic issue of high energy consumption in existing buildings and retrofitting measurers has been receiving increasing attention over the recent decade in the extant literature. There have been a number of research revised on various observations on this perspective, few of these are namely by Khairi,Jaapar And Yahya[2017]which promotes retrofitting as most environmentally friendly, economically competent and proven efficient solution to optimize the energy performance in existing buildings and as well the historic buildings through comparison of various analogous studies. Shaikh, Sahito, UqaliAndUmrani[2017] stated about the cost effective optimization of retrofitting for energy efficiency and various retrofittingscenarios has been discussed for most effective pre retrofit plan. Jan W. Bleyl [2018]stated through retrofitting many approach to combining energy cost saving with the added values of mpbs to enhance their business can appears to be enhance.

**Table 1 Summary of key findings from previous studies**

| Author | Research year | Research approach | conclusions |
|---|---|---|---|
| Braid | 2017 | Systematic approach | Factors affecting energy consumption, factors to be considered when are assessing the energy performance of the buildings and various aspects of energy performance of buildings. |
| Shaikh, Sahito , Uqaili and Umrani | 2017 | Economic approach | Understanding challenges for cost-effective optimal retrofitting within buildings to attain energy standards Conservation and sustainability. |
| Panel. ,Burman and .Mumovic | 2017 | Analytical approach | The study of main protocols And standards used in the Construction industry for Measurement and verification (M&V)of retrofit Projects |
| M.A.Paya and Marin | 2017 | Economic approach | Economic study of both unglazed transpired solar air collector (UTSAC) and back-pass solar air collector (BPSAC) systems, taking into account the internal rate of return and installation cost, based on large-scale test setups and measured performance data. |
| Belany ,Bolf ,Novak, Roch and Otcenasova A | 2018 | Analytical approach | Describes the issue of power consumption of buildings |
| Xiaonuan, Zhonghua and Siu-Yu Lau | 2018 | Systematic approach | Active and passive strategies 14 should be integrated Into building Design to Optimize the energy performance. |

## II. Research Methodology

Assessment of building performance by its baseline to propose for Retrofitting of building services for an energy efficient building is achievedwith two stage methodology a building was chosen which is Fletcher Bhawan of CSS Haryana Agricultural University, Hisar (an administrative building) initially site visits and observation of the above two buildings were carried out and the data is then computed to calculate the current energy performance index of the building as per energy conservation code. And secondly through using Delphi technique of analytic hierarchy process (AHP) a decision making of proposed retrofitted building services are concluded.

## III. Case Studies

For the optimisation of most retrofitted building services for reducing energy consumption in existing building various existing buildings are taken up as case studies The building's design is discussed in the beginning and its type of usage identified followed by a survey of the services systems as well as building use pattern. Scope for energy savings are then identified in each of these systems and retrofit measures are recommended. The overall savings as a cumulative effect of each of the individual measures on the system as a whole is calculated and evaluated in terms of payback period in years.

1. **The Godrej Bhavan Building, Mumbai** This case study highlights Godrej Bhavan, an iconic office building in South Mumbai, focusing on the strong business case for energy-efficiency retrofits. The building was retrofitted with three energy efficient technologies: HVAC by TRANE, lighting by PHILIPES and building management system by TRANE
2. **Retrofitting Mahindra Towers, Mumbai**This case study highlights the Mahindra towers headquarters, an office building in Mumbai, focusing on the strong business case for the ESCO model to implement energy efficiency improvement measures. The energy auditing was carried out for lighting and HVAC system for reducing energy consumption in building by replacing new chiller system with the baseline one.
3. **Global Education Centre (GEC)-1 in the Mysore campus**this case study includes the retrofitting of old chiller plant with less number of new valves and beams to reduce the energy consumption of building.
4. **Express Tower, Mumbai**the building fell under major energy efficient retrofitting successive study as various services were retrofitted to give new life to the building including plumbing lighting electrical and HVAC etc.

**Table 2 conclusion for most opted retrofitting services**

| S. No. | | The Godrej Bhavan Building In Mumbai | Retrofitting Mahindra Towers | Express Tower Mumbai | Global Education Centre (GEC)-1 |
|---|---|---|---|---|---|
| 1. | **Location** | Fort, South Mumbai | Worli, Mumbai, India | Nariman point, Mumbai | Mysore campus |
| 2. | **Building Gross Area** | 3,826 square meters (41,185 square feet) | 18,430 Square Meters (198,277 Square Feet) | 400,000sqft | 440,000 sq. ft |
| 3. | **Building Use:** | Commercial | Commercial | Commercial | Institutional |
| 4. | **Construc ted:** | 1972 | 1985 | 1972 | 2008 |
| 5. | **Retrofit Complete d** | 2010 | March-July 2009 | 2008-2013 | September 2011 |
| 6. | **Project Cost** | Rs 5,384,000 ($99,704) | Rs.40,73,310 ($66,200) | 900 crore | |
| 7. | **Project Type** | Existing Building Renovation Or Retrofit | Existing Building Renovation Or Retrofit | Existing Building Renovation Or Retrofit | Existing Building Renovation Or Retrofit |
| 8. | **Pay Back Period** | 02 years | less than half year | 05 Years | 2 years |
| 9. | **Retrofitt ed Services** | **HVAC**<br>**Lighting**<br>BMS | **HVAC**<br>**Lighting** | **HVAC**<br>**Lighting**<br>Pumps<br>Chiller system<br>Building | **HVAC** |

Resulting to the conclusion of case studies HVAC and Lighting are the most energy consuming services in any building .so, the further study will elaborate the decision making for HVAC and Lighting services as well there reliability by taking various examples and calculating the energy performance index of existing building.

## IV. Energy Performance Index

The Energy Performance Index (EPI) of a building is its annual energy consumption in kilowatt-hours per square meter of the building. While calculating the EPI of a building, the area of unconditioned basements shall not be included. EPI can be determined by:

**EPI = Annual Energy Consumption (KWH) / Total Built-up Area – (unconditioned area)**

### 5. BASELINE ASSESSMENT OF BUILDING PERFORMANCE

**Building: Fletcher Bhawan of CSS Haryana Agricultural University, Hisar**

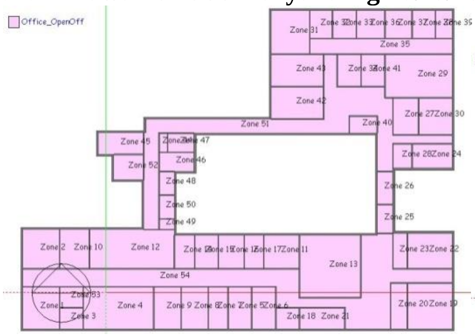

**Figure 2 Ground Floor Plan**

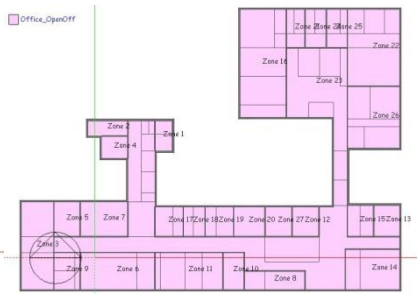

**Figure 3 First Floor Plan**

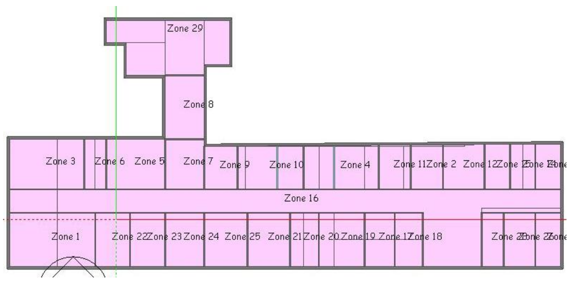

**Figure 4 View of The Building**

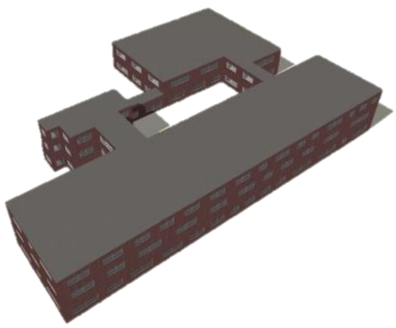

**Figure 5 Second Floor Plan**

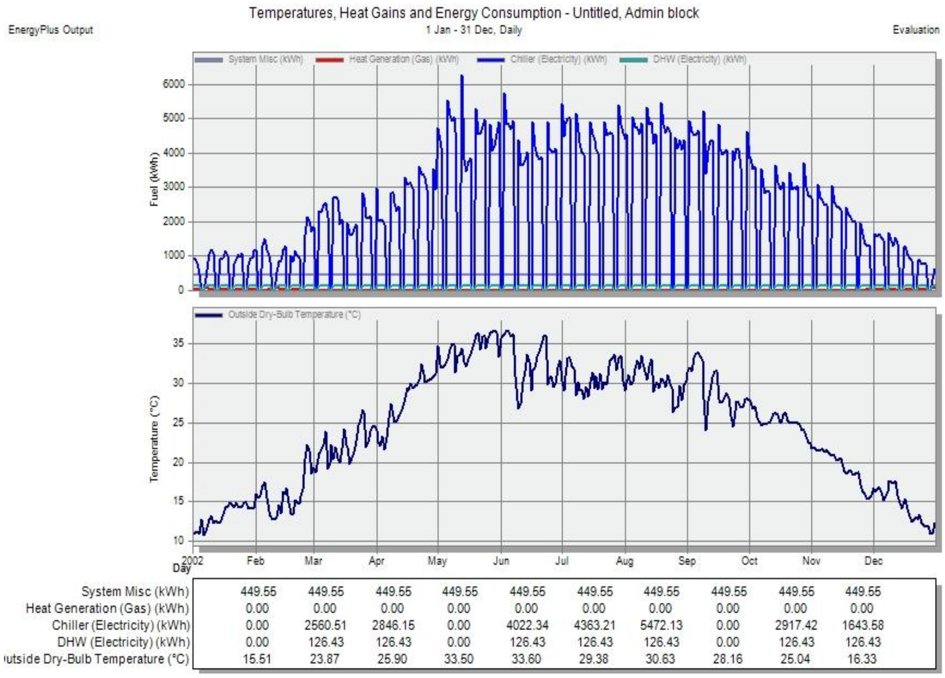


**Figure 6 Monthly Report of HVAC Energy Consumption (Design Builder Software)**

By simulating the building on design builder for hvacHence the total power consumption per m2 per **annum EXISTING= 1116180kwh/yrs**Total built up area: **4352 Sqm**

**Table 3 Admin Building Total Baseline Energy Performance Index**

| For Admin Block (Day Time Occupancy 9hours) | Actual Power Consumption |
|---|---|
| **HVAC** | **1116180 kwh/yr** |
| **Lighting** | **85831 kwh/yr** |
| **Total** | **1124711** |
| **Built-Up Area** | **4532.3 Sqm** |
| **EPI** | **265.6 kW-hr/m2/yr** |

And for lighting manual calculations has been done for appliances to calculate the existing Energy Performance Index.

**Table 4 Energy Performance Index of Admin Block**

| Appliance | Total appliances of G.F | No.of hours used | Total appliances of F.F | No.of hours used | Total appliances of S.F | No.of hours used | TOTAL APPLIANCE /hr | Watt | TOTAL WATT |
|---|---|---|---|---|---|---|---|---|---|
| Ceiling Fan | 90 | 8 | 59 | 8 | 30 | 8 | 1432 | 70 | 100240 |
| Desktop Computer | 29 | 6 | 35 | 6 | 19 | 6 | 498 | 250 | 124500 |
| T12 Fluorescent Tubes | 155 | 8 | 92 | 8 | 50 | 8 | 2376 | 34 | 80784 |
| 32 Inch LED TV | 12 | 4 | 4 | 4 | 19 | 4 | 140 | 50 | 7000 |
| light bulb | 21 | 9 | 16 | 9 | 4 | 9 | 369 | 60 | 22140 |
| light bulb (Incandescent) | 36 | 9 | 21 | 9 | 12 | 9 | 621 | 100 | 62100 |
| Phone Charger | 59 | 9 | 46 | 9 | 26 | 9 | 1179 | 7 | 8253 |
| Projector | 4 | 1 | 1 | 1 | 1 | 1 | 6 | 250 | 1500 |
| Scanner | 4 | 1 | 3 | 1 | 0 | 1 | 7 | 15 | 105 |
| Water Filter and Cooler | 6 | 24 | 7 | 24 | 2 | 24 | 312 | 90 | 28080 |
| Exhaust Fan | 14 | 1 | 11 | 2 | 17 | 2 | 70 | 12 | 840 |
| Microwave | 1 | 1 | 2 | 2 | 0 | 2 | 5 | 700 | 3500 |
| Electric Kettle | 2 | 1 | 1 | 2 | 0 | 2 | 4 | 1200 | 4800 |
| Electric Stove | 1 | 1 | 1 | 2 | 0 | 2 | 3 | 900 | 2700 |
| Fridge / Freezer | 1 | 1 | 3 | 2 | 0 | 2 | 7 | 300 | 2100 |
| Internet Router | 14 | 24 | 11 | 24 | 15 | 24 | 960 | 15 | 14400 |
| Printing Machine | 0 | 0 | 4 | 9 | 0 | 0 | 36 | 300 | 10800 |
| Lift | 1 | 9 | 0 | 9 | 0 | 0 | 9 | 333 | 2997 |
| | | | | **Total watt per day** | | **476839** | **Watt** | | |
| | | | | **Load in kwh** | | **476.83** | **Kwh** | | |
| | | | | **Load in one month** | | **14305** | **kwh/m** | | |
| | | | | **Load in one year** | | **85831** | **kwh/Yr** | | |
| | | | | **Cooling load kwh/yr** | | **1116180** | **kwh/Yr** | | |
| | | | | **Total load** | | **1202011** | **kwh/Yr** | | |
| | | | | **Built up area** | | **4532** | **sqm** | | |
| | | | | **EPI** | | **265.2099 kwh/yr/m2** | | | |

**Hence the total power consumption per m2 per annum EXSTING = 265.2099 kwh/yr/m2**
**As per energy conservation code**

| Energy Performance Index Benchmarks (EPI) – (kWh/ m²/year) | | |
|---|---|---|
| Climate Classification | Day time occupancy | 24 hours Occupancy |
| | 5 Days a week | 7 Days a week |
| Commercial/Institutional/Academic/Hospital buildings | | |
| Moderate | 75 | 225 |
| Composite / Warm and humid / hot and dry | 90 | 300 |
| Residential buildings/Hostels | | |
| Moderate | 50 | |
| Composite / Warm and humid / hot and dry | 70 | |

**Hence, The building is day time occupancy admin building in composite climate of hisar ,Haryana with required EPI 90kwh/yr/m2 so to achieve the required EPI retrofitting is needed.**

## 6. DECISION MAKING FACTORS (PARAMETERS) FOR SERVICES (PROPOSED DESIGN) with analytic hierarchy process (AHP)

### HVAC TYPES

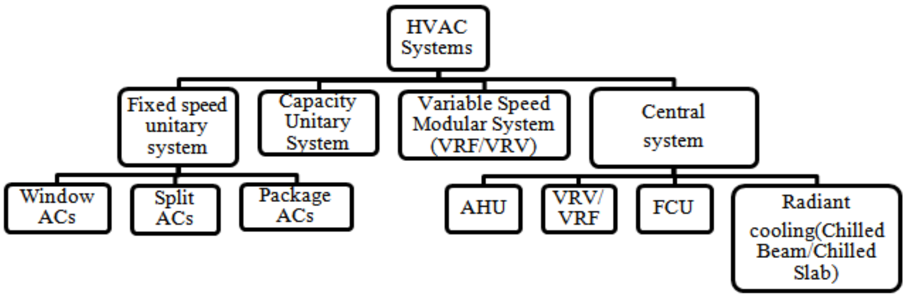


**Figure 7 Various Types of HVAC Systems Discussed in Analysis (source: NBC 2016)**

**Parameters Considered (source: NBC 2016)**

- Temperature Control
- Relative Humidity Control
- Space Pressure Control
- Capacity Requirements
- Spatial Optimization
- Electricity Distribution
- Initial Cost
- Operational Cost
- Maintenance Cost
- Reliability
- Flexibility
- Noise Reduction
- Easy Installation
- Zone-ability

## 8. MPC (Matrix Parametric Comparison) Tables

**Table 5 MPC for Temperature Control**

| **Temperature Control** | | | | | | |
|---|---|---|---|---|---|---|
| Criterion | Fixed Speed Unitary System | Capacity Unitary System | Variable Speed Modular System | Centeral System | Eigen Value | Normalised Eigen Vector |
| Fixed Speed Unitary System | 1.00 | 1.00 | 0.14 | 0.11 | 4.0079 | **0.056** |
| Capacity Unitary System | 1.00 | 1.00 | 0.14 | 0.11 | 4.0079 | **0.056** |
| Variable Speed Modular System | 7.00 | 7.00 | 1.00 | 1.00 | 4.0079 | **0.416** |
| Centeral System | 9.00 | 9.00 | 1.00 | 1.00 | 4.2218 | **0.472** |
| Sum Total | 18.00 | 18.00 | 2.29 | 2.22 | 16.25 | 1.00 |

**Table 6 MPC for relative Humidity control**

| **Relative Humidity Control** | | | | | | |
|---|---|---|---|---|---|---|
| Criterion | Fixed Speed Unitary System | Capacity Unitary System | Variable Speed Modular System | Centeral System | Eigen Value | Normalised Eigen Vector |
| Fixed Speed Unitary System | 1.00 | 1.00 | 0.20 | 0.14 | 4.2818 | **0.060** |
| Capacity Unitary System | 1.00 | 1.00 | 0.14 | 0.14 | 4.2818 | **0.057** |
| Variable Speed Modular System | 5.00 | 7.00 | 1.00 | 0.20 | 4.2818 | **0.251** |
| Centeral System | 7.00 | 7.00 | 5.00 | 1.00 | 4.2818 | **0.632** |
| Sum Total | 14.00 | 16.00 | 6.34 | 1.49 | 17.13 | 1.00 |

**Table 7 MPC for Space Pressure Control**

| **Space Pressure Control** | | | | | | |
|---|---|---|---|---|---|---|
| Criterion | Fixed Speed Unitary System | Capacity Unitary System | Variable Speed Modular System | Centeral System | Eigen Value | Normalised Eigen Vector |
| Fixed Speed Unitary System | 1.00 | 1.00 | 1.00 | 1.00 | 4.0000 | **0.250** |
| Capacity Unitary System | 1.00 | 1.00 | 1.00 | 1.00 | 4.0000 | **0.250** |
| Variable Speed Modular System | 1.00 | 1.00 | 1.00 | 1.00 | 4.0000 | **0.250** |
| Centeral System | 1.00 | 1.00 | 1.00 | 1.00 | 4.0000 | **0.250** |
| Sum Total | 4.00 | 4.00 | 4.00 | 4.00 | 16.00 | 1.00 |

**Table 8 MPC for Capacity Requirements**

| **Capacity Requirements** | | | | | | |
|---|---|---|---|---|---|---|
| Criterion | Fixed Speed Unitary System | Capacity Unitary System | Variable Speed Modular System | Centeral System | Eigen Value | Normalised Eigen Vector |
| Fixed Speed Unitary System | 1.00 | 1.00 | 0.14 | 0.11 | 8.9360 | **0.051** |
| Capacity Unitary System | 1.00 | 1.00 | 0.14 | 9.00 | 8.9358 | **0.328** |
| Variable Speed Modular System | 7.00 | 7.00 | 1.00 | 0.20 | 8.9360 | **0.342** |
| Centeral System | 9.00 | 0.11 | 5.00 | 1.00 | 8.9364 | **0.278** |
| Sum Total | 18.00 | 9.11 | 6.29 | 10.31 | 35.74 | 1.00 |

**Table 9 MPC for spatial optimization**

| **Spatial Optimization** | | | | | | |
|---|---|---|---|---|---|---|
| Criterion | Fixed Speed Unitary System | Capacity Unitary System | Variable Speed Modular System | Centeral System | Eigen Value | Normalised Eigen Vector |
| Fixed Speed Unitary System | 1.00 | 1.00 | 0.20 | 0.20 | 4.1545 | **0.078** |
| Capacity Unitary System | 1.00 | 1.00 | 0.20 | 0.20 | 4.1545 | **0.078** |
| Variable Speed Modular System | 5.00 | 5.00 | 1.00 | 0.33 | 4.1545 | **0.305** |
| Centeral System | 5.00 | 5.00 | 3.00 | 1.00 | 4.1545 | **0.538** |
| Sum Total | 12.00 | 12.00 | 4.40 | 1.73 | 16.62 | 1.00 |

**Table 10 MPC for Electricity Distribution**

| Electricity Distribution | | | | | | |
|---|---|---|---|---|---|---|
| Criterion | Fixed Speed Unitary System | Capacity Unitary System | Variable Speed Modular System | Centeral System | Eigen Value | Normalised Eigen Vector |
| Fixed Speed Unitary System | 1.00 | 0.33 | 3.00 | 0.20 | 5.1135 | **0.133** |
| Capacity Unitary System | 3.00 | 1.00 | 0.33 | 0.20 | 5.1135 | **0.136** |
| Variable Speed Modular System | 0.33 | 3.00 | 1.00 | 0.11 | 5.1135 | **0.127** |
| Centeral System | 5.00 | 5.00 | 9.00 | 1.00 | 5.1135 | **0.604** |
| Sum Total | 9.33 | 9.33 | 13.33 | 1.51 | 20.45 | 1.00 |

**Table 11 MPC for initial cost**

| Initial Cost | | | | | | |
|---|---|---|---|---|---|---|
| Criterion | Fixed Speed Unitary System | Capacity Unitary System | Variable Speed Modular System | Centeral System | Eigen Value | Normalised Eigen Vector |
| Fixed Speed Unitary System | 1.00 | 1.00 | 5.00 | 7.00 | 7.0397 | **0.427** |
| Capacity Unitary System | 1.00 | 1.00 | 5.00 | 0.14 | 7.0397 | **0.192** |
| Variable Speed Modular System | 0.20 | 0.20 | 1.00 | 3.00 | 7.0397 | **0.140** |
| Centeral System | 0.14 | 7.00 | 0.33 | 1.00 | 7.0397 | **0.241** |
| Sum Total | 2.34 | 9.20 | 11.33 | 11.14 | 28.16 | 1.00 |

**Table 12 MPC for operational cost**

| Operational Cost | | | | | | |
|---|---|---|---|---|---|---|
| Criterion | Fixed Speed Unitary System | Capacity Unitary System | Variable Speed Modular System | Centeral System | Eigen Value | Normalised Eigen Vector |
| Fixed Speed Unitary System | 1.00 | 1.00 | 0.20 | 0.11 | 4.0328 | **0.060** |
| Capacity Unitary System | 1.00 | 1.00 | 0.20 | 0.11 | 4.0328 | **0.060** |
| Variable Speed Modular System | 5.00 | 5.00 | 1.00 | 0.33 | 4.0328 | **0.265** |
| Centeral System | 9.00 | 9.00 | 3.00 | 1.00 | 4.0328 | **0.616** |
| Sum Total | 16.00 | 16.00 | 4.40 | 1.56 | 16.13 | 1.00 |

**Table 13 MPC for Maintenance Cost**

| Maintenance Cost | | | | | | |
|---|---|---|---|---|---|---|
| Criterion | Fixed Speed Unitary System | Capacity Unitary System | Variable Speed Modular System | Centeral System | Eigen Value | Normalised Eigen Vector |
| Fixed Speed Unitary System | 1.00 | 1.00 | 1.00 | 0.33 | 4.0000 | **0.167** |

| | | | | | | |
|---|---|---|---|---|---|---|
| Capacity Unitary System | 1.00 | 1.00 | 1.00 | 0.33 | 4.0000 | **0.167** |
| Variable Speed Modular System | 1.00 | 1.00 | 1.00 | 0.33 | 4.0000 | **0.167** |
| Centeral System | 3.00 | 3.00 | 3.00 | 1.00 | 4.0000 | **0.500** |
| Sum Total | 6.00 | 6.00 | 6.00 | 2.00 | 16.00 | 1.00 |

**Table 14 MPC for Reliability**

| **Reliability** | | | | | | |
|---|---|---|---|---|---|---|
| Criterion | Fixed Speed Unitary System | Capacity Unitary System | Variable Speed Modular System | Centeral System | Eigen Value | Normalised Eigen Vector |
| Fixed Speed Unitary System | 1.00 | 1.00 | 1.00 | 0.20 | 4.0328 | **0.132** |
| Capacity Unitary System | 1.00 | 1.00 | 1.00 | 0.20 | 4.0328 | **0.132** |
| Variable Speed Modular System | 1.00 | 1.00 | 1.00 | 0.33 | 4.0328 | **0.151** |
| Centeral System | 5.00 | 5.00 | 3.00 | 1.00 | 4.0328 | **0.585** |
| Sum Total | 8.00 | 8.00 | 6.00 | 1.73 | 16.13 | 1.00 |

**Table 15 MPC for flexibility**

| **Flexibility** | | | | | | |
|---|---|---|---|---|---|---|
| Criterion | Fixed Speed Unitary System | Capacity Unitary System | Variable Speed Modular System | Centeral System | Eigen Value | Normalised Eigen Vector |
| Fixed Speed Unitary System | 1.00 | 1.00 | 0.11 | 5.00 | 6.4203 | **0.170** |
| Capacity Unitary System | 1.00 | 1.00 | 1.00 | 0.20 | 6.4203 | **0.138** |
| Variable Speed Modular System | 9.00 | 9.00 | 1.00 | 9.00 | 6.4203 | **0.548** |
| Centeral System | 0.20 | 0.33 | 0.11 | 1.00 | 6.4203 | **0.145** |
| Sum Total | 11.20 | 11.33 | 2.22 | 15.20 | 25.68 | 1.00 |

**Table 16 MPC for noise reduction**

| **Noise Reduction** | | | | | | |
|---|---|---|---|---|---|---|
| Criterion | Fixed Speed Unitary System | Capacity Unitary System | Variable Speed Modular System | Centeral System | Eigen Value | Normalised Eigen Vector |
| Fixed Speed Unitary System | 1.00 | 1.00 | 1.00 | 0.14 | 4.1545 | **0.098** |
| Capacity Unitary System | 1.00 | 1.00 | 3.00 | 0.14 | 4.1545 | **0.135** |
| Variable Speed Modular System | 1.00 | 0.33 | 1.00 | 0.14 | 4.1545 | **0.077** |
| Centeral System | 7.00 | 7.00 | 7.00 | 1.00 | 4.1545 | **0.689** |
| Sum Total | 10.00 | 9.33 | 12.00 | 1.43 | 16.62 | 1.00 |

**Table 17 MPC for easy installation**

| **Easy Installation** | | | | | | |
|---|---|---|---|---|---|---|
| Criterion | Fixed Speed Unitary System | Capacity Unitary System | Variable Speed Modular System | Centeral System | Eigen Value | Normalised Eigen Vector |
| Fixed Speed Unitary System | 1.00 | 1.00 | 1.00 | 9.00 | 4.0000 | **0.321** |
| Capacity Unitary System | 1.00 | 1.00 | 1.00 | 9.00 | 4.0000 | **0.321** |
| Variable Speed Modular System | 1.00 | 1.00 | 1.00 | 9.00 | 4.0000 | **0.321** |
| Centeral System | 0.11 | 0.11 | 0.11 | 1.00 | 4.0000 | **0.036** |
| Sum Total | 3.11 | 3.11 | 3.11 | 28.00 | 16.00 | 1.00 |

**Table 18 MPC for zonability**

| **Zonability** | | | | | | |
|---|---|---|---|---|---|---|
| Criterion | Fixed Speed Unitary System | Capacity Unitary System | Variable Speed Modular System | Centeral System | Eigen Value | Normalised Eigen Vector |
| Fixed Speed Unitary System | 1.00 | 1.00 | 7.00 | 3.00 | 5.1146 | **0.502** |
| Capacity Unitary System | 1.00 | 1.00 | 0.33 | 3.00 | 5.1146 | **0.191** |
| Variable Speed Modular System | 3.00 | 3.00 | 1.00 | 5.00 | 5.1146 | **0.239** |
| Centeral System | 0.33 | 0.33 | 0.20 | 1.00 | 5.1146 | **0.068** |
| Sum Total | 5.33 | 5.33 | 8.53 | 12.00 | 20.46 | 1.00 |

**MPC for parameters**

| PARAMETERS | Temperature Control | Relative Humidity Control | Space Pressure Control | Capacity Requirements | Spatial Optimization | Electricity Distribution | Initial Cost | operational cost | Maintenance Cost | Reliability | Flexibility | Noise Reduction | Easy Installation | Zonability | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temperature Control | 1.00 | 0.20 | 0.20 | 0.14 | 0.14 | 7.00 | 5.00 | 0.14 | 5.00 | 9.00 | 0.14 | 0.11 | 5.00 | 3.00 | 36.08 |
| Relative Humidity Control | 5.00 | 1.00 | 0.33 | 5.00 | 0.11 | 9.00 | 0.14 | 0.11 | 0.20 | 7.00 | 0.20 | 0.20 | 0.14 | 0.20 | 28.64 |
| Space Pressure Control | 5.00 | 3.00 | 1.00 | 3.00 | 0.33 | 5.00 | 0.33 | 0.33 | 5.00 | 0.33 | 0.20 | 0.20 | 0.33 | 0.33 | 24.40 |
| Capacity Requirements | 7.00 | 0.20 | 0.33 | 1.00 | 0.20 | 0.33 | 0.33 | 5.00 | 3.00 | 5.00 | 0.33 | 0.20 | 0.33 | 0.20 | 23.47 |
| Spatial Optimization | 7.00 | 9.00 | 3.00 | 5.00 | 1.00 | 5.00 | 0.33 | 3.00 | 5.00 | 7.00 | 5.00 | 0.33 | 0.20 | 0.33 | 51.20 |
| Electricity Distribution | 0.14 | 0.11 | 0.20 | 3.00 | 0.20 | 1.00 | 0.33 | 0.20 | 0.33 | 5.00 | 3.00 | 0.33 | 3.00 | 0.33 | 17.19 |
| Initial Cost | 0.20 | 7.00 | 3.00 | 3.00 | 3.00 | 3.00 | 1.00 | 5.00 | 5.00 | 7.00 | 0.20 | 0.14 | 0.33 | 0.14 | 38.02 |
| operational cost | 7.00 | 9.00 | 3.00 | 0.20 | 0.33 | 5.00 | 0.20 | 1.00 | 5.00 | 3.00 | 5.00 | 0.33 | 0.33 | 0.33 | 39.73 |
| Maintenance Cost | 0.20 | 5.00 | 0.20 | 0.33 | 0.20 | 3.00 | 0.20 | 0.20 | 1.00 | 0.20 | 0.20 | 0.33 | 0.20 | 0.11 | 11.38 |
| Reliability | 0.11 | 0.14 | 3.00 | 0.20 | 0.14 | 0.20 | 0.14 | 0.33 | 5.00 | 1.00 | 0.33 | 0.20 | 0.20 | 0.11 | 11.12 |
| Flexibility | 7.00 | 5.00 | 5.00 | 3.00 | 0.20 | 0.33 | 5.00 | 0.20 | 5.00 | 3.00 | 1.00 | 0.20 | 7.00 | 0.20 | 42.13 |
| Noise Reduction | 9.00 | 5.00 | 5.00 | 5.00 | 3.00 | 3.00 | 7.00 | 3.00 | 3.00 | 5.00 | 5.00 | 1.00 | 5.00 | 5.00 | 64.00 |
| Easy Installation | 0.20 | 7.00 | 3.00 | 3.00 | 5.00 | 0.33 | 3.00 | 3.00 | 5.00 | 5.00 | 0.14 | 0.20 | 1.00 | 0.20 | 36.08 |
| Zonability | 0.33 | 5.00 | 3.00 | 5.00 | 3.00 | 3.00 | 7.00 | 3.00 | 9.00 | 9.00 | 5.00 | 0.20 | 5.00 | 1.00 | 58.53 |
| EIGEN VALUE | 60.74728 | 60.74728 | 60.74728 | 60.74728 | 60.74728 | 60.7472 | 60.74728 | 60.74728 | 60.74728 | 60.74728 | 60.74728 | 60.74728 | 60.74728 | 60.747 | 850.46 |
| NORMALISED EIGEN VECTOR | 0.10 | 0.11 | 0.06 | 0.08 | 0.03 | 0.12 | 0.05 | 0.05 | 0.13 | 0.16 | 0.04 | 0.01 | 0.06 | 0.02 | 1.00 |

**MPC for ranking HVAC systems**

| | WEIGHTAGES | Fixed Speed Unitary System | | Capacity Unitary System | | Variable Speed Modular System | | Centeral system | |
|---|---|---|---|---|---|---|---|---|---|
| Temperature Control | 0.097854459 | **0.056** | 0.005455451 | **0.056** | 0.005455451 | **0.416** | 0.040749433 | **0.472** | 0.046194124 |
| Relative Humidity Control | 0.109915724 | **0.060** | 0.006607263 | **0.057** | 0.006238826 | **0.251** | 0.027607281 | **0.632** | 0.069462354 |
| Space Pressure Control | 0.058700163 | **0.250** | 0.014675041 | **0.250** | 0.014675041 | **0.250** | 0.014675041 | **0.250** | 0.014675041 |
| Capacity Requirements | 0.076249441 | **0.051** | 0.003920785 | **0.328** | 0.02503237 | **0.342** | 0.026073244 | **0.278** | 0.021223042 |
| Spatial Optimization | 0.027929045 | **0.078** | 0.002186654 | **0.078** | 0.002186654 | **0.305** | 0.008520603 | **0.538** | 0.015035135 |
| Electricity Distribution | 0.122078065 | **0.133** | 0.016206732 | **0.136** | 0.01665799 | **0.127** | 0.015454223 | **0.604** | 0.07375912 |
| Initial Cost | 0.051209 | **0.427** | 0.021858 | **0.192** | 0.009849 | **0.140** | 0.007174 | **0.241** | 0.012328 |
| operational cost | 0.04643386 | **0.060** | 0.00277217 | **0.060** | 0.00277217 | **0.265** | 0.0122846 | **0.616** | 0.02860493 |
| Maintenance Cost | 0.1264677 | **0.167** | 0.021078 | **0.167** | 0.021078 | **0.167** | 0.021078 | **0.500** | 0.0632339 |
| Reliability | 0.1580084 | **0.132** | 0.02085116 | **0.132** | 0.02085116 | **0.151** | 0.02390612 | **0.585** | 0.09239996 |
| Flexibility | 0.0399 | **0.170** | 0.00679005 | **0.138** | 0.00550192 | **0.548** | 0.02187716 | **0.145** | 0.00577428 |
| Noise Reduction | 0.01 | **0.098** | 0.000842044 | **0.135** | 0.001157956 | **0.077** | 0.000656228 | **0.689** | 0.005894308 |
| Easy Installation | 0.05650431 | **0.321** | 0.0181621 | **0.321** | 0.0181621 | **0.321** | 0.0181621 | **0.036** | 0.00201801 |
| Zonability | 0.0201562 | **0.502** | 0.0101259 | **0.191** | 0.0038473 | **0.239** | 0.0048169 | **0.068** | 0.0013662 |
| FINAL DESIRABILITY | 1 | | 0.151531 | | 0.1534661 | | 0.2430344 | | 0.4519685 |
| RANKING | | | 4 | | 3 | | 2 | | 1 |

Hence, it is seen that the best option for the HVAC system type would be Central system, as it ranks 1st. The 2nd best option is Variable Speed Modular System.

## V. Conclusion:

This is assessment methodology for integrated decision making in active energy efficiency of existing buildings. This Paper Presented the Possible Assessment of Building Energy Performance and the Decision Making technique to identify the best system out of available systems as per engineers and field HVAC consultants for particular government building. For future study this study can be justified by simulating the proposed systems as per AHP process and identifying the Energy Performance Index in ECBC limits and within projects payback period limits to justify its economic feasibility. This study can be applied on any commercial, educational, recreational and many official government building.

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