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# Simulation of Operational Faults of Heating, Ventilation and Air Conditioning Systems Compromising Energy Consumption for Abu Dhabi Future Schools (ADFS)

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***Abstract:*** **Previous studies show that a massive amount of energy is consumed by Heating, Ventilation and Air Conditioning (HVAC) systems, around 40% globally. In the UAE, the energy consumed by HVAC sometimes exceeds 60% of the total energy usage. Malfunctioning controls and a lack of regular maintenance schedules are the main reasons behind that. The malfunctioning plant and equipment require troubleshooting to ensure the desired cost-effective operation. This study investigates HVAC systems to increase their energy efficiency. Structures that maximise efficiency and operational controls can enhance the energy performance of buildings. This will maintain HVAC system design performance and reduce maintenance costs. The method for this study used the energy modelling process in order to simulate the operational faults of HVAC equipment using the Abu Dhabi Future Schools programme as a case study. In this process IESVE Software was used to run different models. The results illustrated that the overall power consumption was increased due to the operational faults of HVAC. This will help to develop performance indicators for HVAC systems in order to reduce the power consumption.**

***Keywords:*** **HVAC Systems, HVAC Maintenance Practices, HVAC system faults, High energy consumption, Conserving energy, HVAC System performance indicators, IESVE, Integrated Environmental Solutions (Virtual Environment), Abu Dhabi Future Schools.**

## 1. INTRODUCTION

Abu Dhabi-UAE has extraordinarily hot temperatures that frequently exceed 52°C which, in the absence of air-conditioning, would be intolerable and would significantly impact on productivity. Most of the energy is consumed by the HVACS (Heating, Ventilation, and Air Conditioning Systems). From previous studies on power consumption, as much as 45% of the total energy used in the building sector goes toward HVAC systems (Kreider *et al.*, 2002). For the Gulf area, consumption reached up to 60% due to the severe temperatures (see Figure 1.1). Following feedback from HVAC maintenance expertise, facility managers confirmed that different faults on HVAC equipment lead to increased power consumption. The existence of faults in HVAC systems plays a significant role in the degradation of comfort levels for building occupants. Analyses of the faults in HVAC systems indicate that the functioning of some components is not in accordance with the design intent. These faults can be classified into two types of component failure: abrupt failure and degradation (Cook *et al.*, 2012).

The Abu Dhabi Future Schools Programme was launched by the government of Abu Dhabi (UAE) and it aims to build 100 new schools and refurbish 50 old ones by 2030. The programme is based on three key pillars: understanding educational needs and community expectations, achieving the highest international standards and producing designs that are safe, sustainable, well built, easy to maintain and appropriate for learning.

Previous studies showed that a massive amount of energy is consumed by HVAC systems, around 40% globally. In UAE the energy consumed by HVAC sometimes exceeds 60% of the total energy usage. The literature review, technical reports and preliminary study conducted with some experts showed that this high energy consumption is due to HVAC equipment's inefficient performance which is related to maintenance activities and malfunctioning of control systems. There is a lack of standard maintenance key performance indicators.

This paper is anticipated to expand the existing knowledge on fault modelling and simulation methods in maintenance applications. The study aims at introducing a set of performance indicators for assessing the performance of maintenance procedures. It can be utilized by maintenance personnel and building managers as a tool to assess the impacts of common operation and maintenance faults on HVAC performance and improve the integration of HVAC systems operations into the overall building maintainability (BM) strategies.

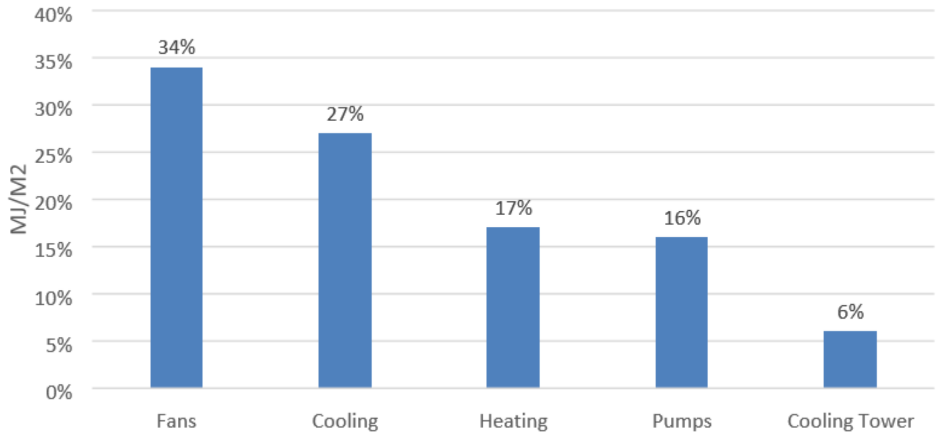


**Figure1: Typical Energy Consumption Breakdown in an HVAC System (Lasath *et al.*, 2012)**

## 2. FAULT INDICATOR MODELS

**Studies by** the Masdar Institute of Science and Technology in Abu Dhabi developed a filter for Air Handling Units (AHU) called a Kalman filter (Figure 2) that accurately identifies certain categories of abnormal conditions that are the most prevalent in hot, humid climates like the UAE. The methodology involved tracking the time-varying parameters of a dynamic linear model. The parameters were estimated using a Kalman filter which elegantly re-adjusts to changes in system states. The results show that the Kalman filter was able to detect faults in the AHU sub-system in a remarkably timely manner (Timothy *et al.*, 2014).

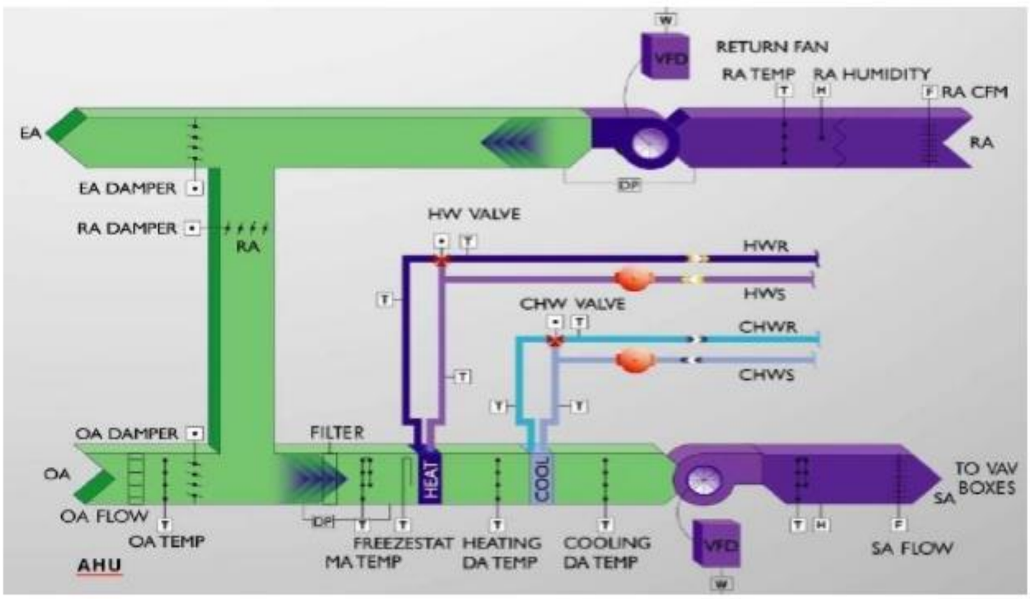


**Figure.2: AHU Schematic with a Kalman Filter (Timothy, 2014)**

## 3. METHOD

The Energy Simulation Modelling in this study used IESVE software. IESVE software helps architects, engineers, academics and researchers to input and analyse the complete building information with environmental analysis function tools. The IESVE dynamic simulation tool helps effectively to analyse building energy consumption behaviour, optimize building performance, recommend best orientation for energy conservation and calculate $CO_2$ emissions **and** energy consumption hourly, daily, weekly, monthly and annually.

In this study the energy simulation modelling will be used to:

- Simulate the design performance of the HVAC system for the Abu Dhabi Future Schools Programme taking into consideration clean and dirty filters and extract the statistical data for monthly and annual energy bills to compare the energy losses.
- Use the model to run different operational faults in order to develop a fault indicator.

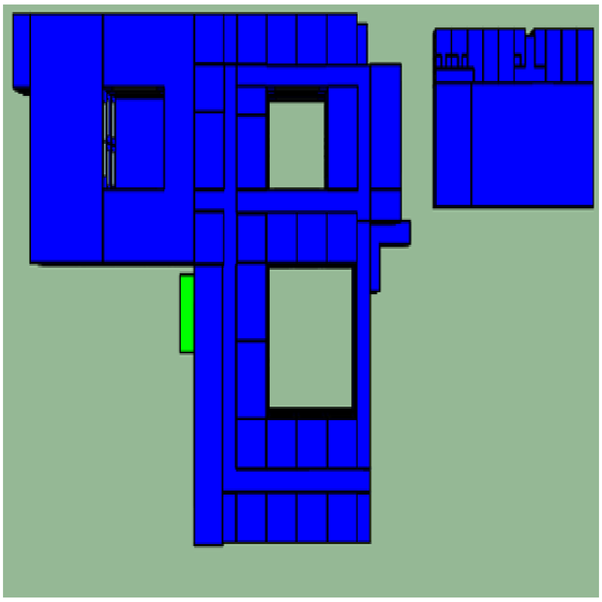

**Figure.3: Baseline building of the ADFS Programme (plan view)**

### 3.1 Building Model Finishes and HVAC System Description:

The building model was generated in IESVE using its dynamic Model IT tool. Upon completion of the building geometry, construction material specifications and specific values were applied to the building geometry such as U-values for Wall, Window, Glass, Roof and building fabric data such as internal heat gains using the ASHRAE 90.1 Navigator tool. Since the building has versatile applications / zones such as class rooms, recreation, fitness, executive meeting rooms and rest rooms, therefore, all different models should be prepared for energy analysis. The building model under simulation has the following construction material combination. The material used in the building construction is selected from Abu Dubai Municipality's approved list of materials and overall heat transfer co-efficient and U-Values are calculated using the calculation sheet provided by the Abu Dubai urban planning centre. The U-values used in both the baseline and proposed cases are kept unchanged due to the limited scope of this study which only concerns the performance of HVAC system maintenance. The subsequent analysis is for the impact on HVAC system maintenance faults, thermal energy consumption, electrical energy consumption and savings and $CO_2$ emissions in all cases.

The HVAC system installed in the building under analysis is a conventional system and is based on Fan Coil Units, Air Handling Units, Fresh Air Handling Units with Heat Recovery, and Heat Exchangers connected with screw chillers. Fan Coil Units have a three speed controller and Air Handling Units have a Constant Air Volume. Private, Public Toilets and Residential Kitchen Extractors are connected to Fresh Air Handling Units.

Lighting Load, Equipment Load and Occupancy used is as per the recommendations of ASHRAE Standard 90.1-2007. In both the Baseline Case and Proposed Case the above parameters remained unchanged throughout the entire modelling process.

**3.2 Building Fabric Data:**

External Wall: Overall heat transfer co-efficient values as per the project specified material in compliance with Abu Dhabi Urban Planning (ESTIDAMA) Regulations and Standard 90.1 were used.

External Window Glazing: Overall heat transfer co-efficient U-vales and shading co-efficient were used as per the material data sheet in compliance with Abu Dhabi Urban Planning (ESTIDAMA) ASHRAE standard 90.1.

**3.3 Modelling Process:**

Following are the different stages of the modelling process using the ASHRAE Standard 90.1 Building Performance Rating Method (BPRM). Energy simulations were run for uncontrolled filter conditions and compared with controlled and monitored filter conditions i.e. clean filters. Due to choked filters, the supply airflow is reduced thus compromising thermal comfort levels, calling for reduced thermostatic set points or BMS-activated set points in order to achieve acceptable levels of thermal comfort. Four stages of reducing the temperature set point by 1 degree centigrade in each run were modelled to record the increase in energy consumption. The baseline set point temperature was 23.89 $^{O}$C and it is reduced by one degree for each run, i.e. 22.89 $^{O}$C, 21.89 $^{O}$C, 20.89 $^{O}$C and 19.89 $^{O}$C. Therefore, all input parameters for interior and exterior heat gain inputs were kept unchanged for all simulation cases. Likewise, the overall heat transfer coefficient (U-Values), shading co-efficient (SC), lighting load, equipment load, occupant density and ventilation rates remained unchanged in both Baseline and Proposed Cases.

***3.3.1 HVAC System Used in** the **Simulation:***

**As can be seen in Figures 4 and 5, the HVAC system used in both the Baseline Case and Proposed Case simulation runs is identical with Chilled-water-based Fan Coil Units, Air Handling Units and Fresh-air Handling Units with a Heat Recovery System. This is the actual system which is installed in Abu Dhabi Future Schools.**

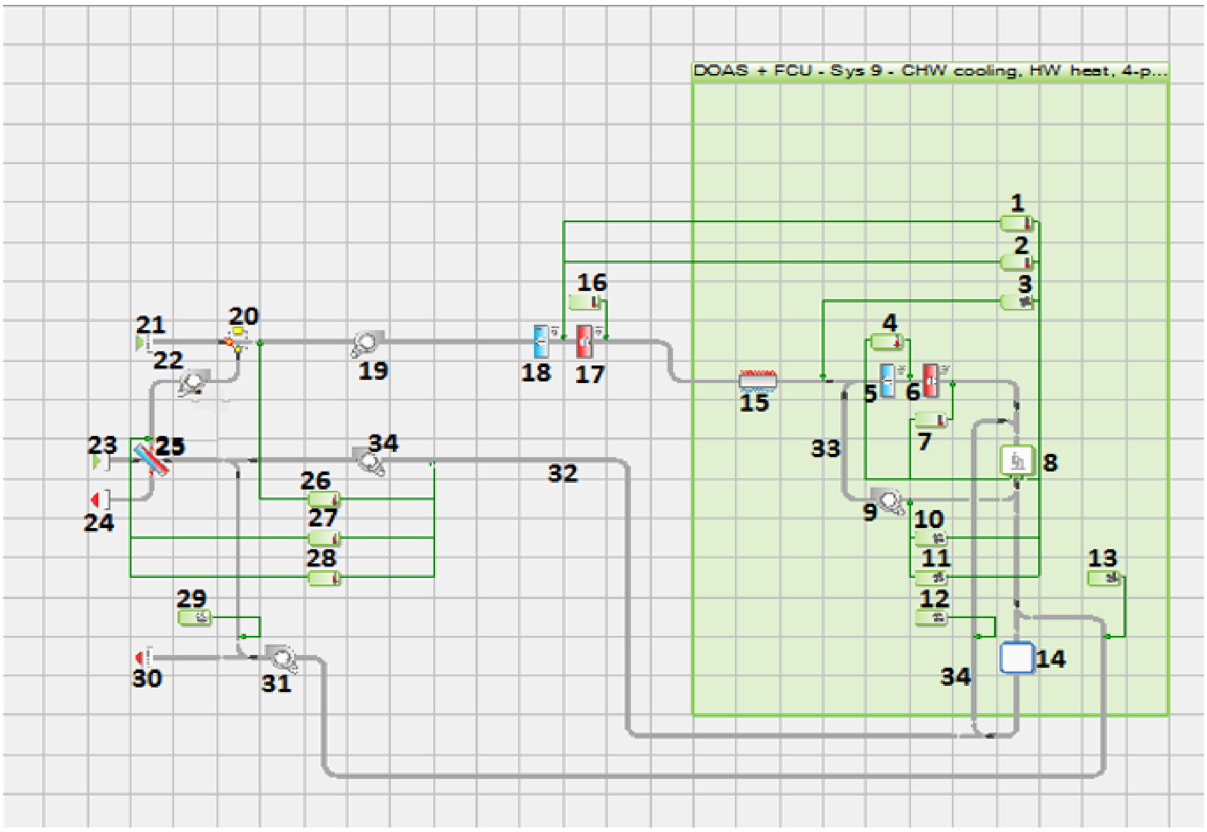


**Figure.4: Baseline System**

The HVAC system shown in Figure 4 is the system used for the baseline case and the system shown in Figure 5 is used for the proposed case. However, both the systems are identical due to the fact that the purpose of this study is to find the impact of faults and human behaviour on energy consumption. The HVAC system description is shown in detail in Table 2.

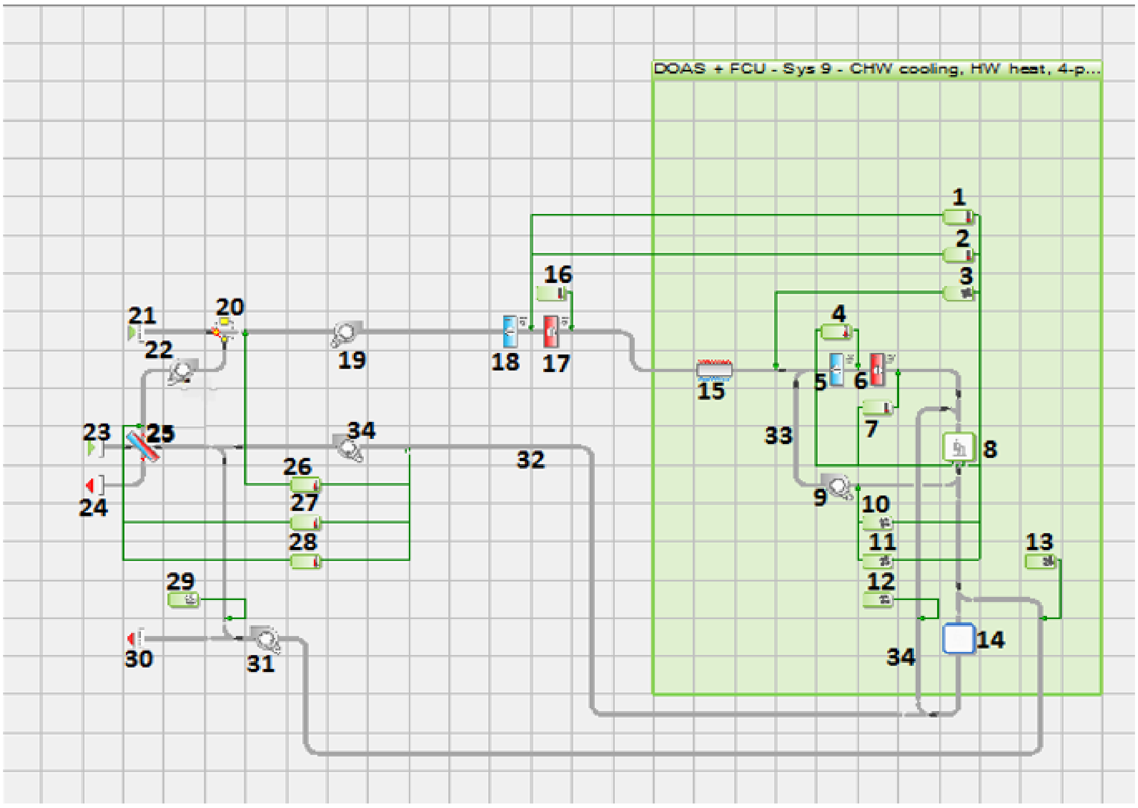


**Figure.5: Proposed System**

**Table.1: HVAC System Component Description**

| | |
|---|---|
| 1. MC1: Cooling coil SAT reset per zone demand | 2. MC2: Cooling SAT reset per zone dehumidification demand |
| 3. MC3: Zone ventilation from DOAS into FCU with DCV option (if no DCV, set flow at min = flow at max) | 4. MC3: Zone ventilation from DOAS into FCU with DCV option (if no DCV, set flow at min = flow at max) |
| 5. M2: FCU Cooling coil | 6. M3: FCU heating coil |
| 7. MC8: FCU heating coil-heat control ramps to Max T before fan steps up (2-speed) or ramps up (VSD) | 8. M1: Principal conditioned space |
| 9. M4: FCU Fan | 10. MC4: FCU heating airflow with 2-SPEED FAN; for VSD FAN, change proportional control band to 2.0 |
| 11. MC5: FCU cooling airflow with 2-SPEED FAN; for VSD FAN, change proportional control band to 2.0 | 12. MC7: Transfer airflow rate -- if EA and no SA, this must be > or = EA |
| 13. MC6: Exhaust Airflow Controller -- zero if none | 14. Return Air Plenum -- match to zone and floor level on each M layer |
| 15. Zone-level SA Duct Heat Gain | 16. SC1: AHU Heating coil controlled to maintain minimum SAT |
| 17. S4: DOAS Heating coil | 18. S3: DOAS Cooling coil |
| 19. S2: SA Fan | 20. S1: Face & Bypass damper set |
| 21. Fresh Air Intake | 22. S8: SA fan - ADDITIONAL Pressure via ER wheel or other HX |
| 23. Fresh Air Intake | 24. Exhaust Air Outlet |
| 25. S7: Energy recovery device | 26. SC3: Energy recovery bypass damper SAT target per RA temp |
| 27. SC4: COOLING mode energy recovery target per RA temp | 28. SC5: HEATING mode energy recovery target per RA temp |
| 29. EA availability for energy recovery (type 0% or 100%) | 30. Exhaust Air Outlet |
| 31. S6: Exhaust Fan - system-level fan (adjust accordingly if local fans) | 32. Exhaust Air Duct |
| 33. FCU Supply/Return Air Duct | 34. Transfer Air Duct |

**Table.2: Simulation Runs for Energy Model File: Future School-All Cases As detailed In The Table**

| | Supply Air Fan Total Static Pressure | Return Air Fan Total Static Pressure | Heat Recovery Wheel Total Static Pressure | Fan Coil Unit Total Static Pressure | System Schedules and Set Points | End Use | | | Internal Lighting | Exterior Lighting | Space Cooling | Pumps |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Design Energy Type | | Electricity | Electricity | Electricity | Electricity |
| | | | | | | | Units | | kWh | kWh | kWh | kWh |
| Proposed | | | | | | Energy Consumption | Building Results | | 582,447 | 43,168 | 1,631,452 | 62,510 |
| Baseline | 1000 Pa | 600 Pa | 250 Pa | 250 Pa | 23.89 °C | Energy Consumption | Building Results | | 582,447 | 43,168 | 1,661,794 | 66,391 |
| | | | | | | Percent Savings | % | | 0 | 0 | 2 | 6 |
| FS_Proposed1 | 1300 Pa | 800 Pa | 350 Pa | 350 Pa | 23.89 °C | Energy Consumption | kWh | | 582,447 | 43,168 | 1,703,950 | 64,767 |
| | | | | | | Percent Savings | % | | 0 | 0 | -3 | 2 |
| FS_Proposed2 | 1600 Pa | 1000 Pa | 350 Pa | 450 Pa | 23.89 °C | Energy Consumption | kWh | | 582,447 | 43,168 | 1,715,660 | 64,091 |
| | | | | | | Percent Savings | % | | 0 | 0 | -3 | 3 |
| FS_Proposed3 | 1600 Pa | 1000 Pa | 350 Pa | 450 Pa | 22.89 °C | Energy Consumption | kWh | | 582,447 | 43,168 | 1,730,285 | 78,582 |
| | | | | | | Percent Savings | % | | 0 | 0 | -4 | -18 |
| FS_Proposed4 | 1600 Pa | 1000 Pa | 350 Pa | 450 Pa | 21.89 °C | Energy Consumption | kWh | | 582,447 | 43,168 | 1,807,034 | 102,229 |
| | | | | | | Percent Savings | % | | 0 | 0 | -9 | -54 |
| FS_Proposed5 | 1600 Pa | 1000 Pa | 350 Pa | 450 Pa | 20.89 °C | Energy Consumption | kWh | | 582,447 | 43,168 | 2,018,306 | 148,251 |
| | | | | | | Percent Savings | % | | 0 | 0 | -21 | -123 |
| FS_Proposed6 | 1600 Pa | 1000 Pa | 350 Pa | 450 Pa | 19.89 °C | Energy Consumption | kWh | | 582,447 | 43,168 | 2,272,499 | 171,700 |
| | | | | | | Percent Savings | % | | 0 | 0 | -37 | -159 |

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Heat Rejection** | Electricity | kWh | 113,043 | 114,576 | 1 | 118,067 | -3 | 118,878 | -4 | 119,891 | -5 | 125,209 | -9 | 139,848 | -22 | 157,461 | -37 |
| **Fans Interior** | Electricity | kWh | 489,796 | 502,776 | 3 | 726,211 | -44 | 803,590 | -60 | 814,602 | -62 | 847,639 | -69 | 913,859 | -82 | 1,092,088 | -117 |
| **Receptacle Equipment** | Electricity | kWh | 405,136 | 405,136 | 0 | 405,136 | 0 | 405,136 | 0 | 405,136 | 0 | 405,136 | 0 | 405,136 | 0 | 405,136 | 0 |
| | | | 3,327,553 | 3,376,288 | 1 | 3,643,747 | -8 | 3,732,971 | -11 | 3,774,112 | -12 | 3,912,863 | -16 | 4,251,016 | -26 | 4,724,500 | -40 |

## 4. RESULT AND FINDINGS

After running the model, Figures 4 and 5 and Table 1 illustrate the findings for running the different models through the IESVE software. The simulation temperature assigned in Building Template Manager is 23.89$^{O}$C to all spaces throughout the day in the two simulation runs in the baseline case with clean filters and in the proposed case with a first stage dirty filter. Another stage of dirty filter was ultimately considered as the optimum level dirt in a filter. This was also simulated. In this stage when a filter is severely choked, the airflow to the space reduces whereby the occupants start feeling uncomfortable and a demand for reducing room set point temperature arises. Considering the increased demand for thermal comfort, the room set point is reduced by one degree centigrade in each of four (04) stages. Each stage simulation is run and energy consumption data is recorded and compared with the baseline case.

## 5. CONCLUSION AND FUTURE REPORTS

The results show an over 40% energy consumption more than the baseline. This is due to the following factors:-

- When the dirt and unwanted fine particles were introduced in the filters.
- Increased room temperatures, i.e., higher than the room set points. Due to the higher room room temperatures chillers, pumps and terminal units keep on working continuously to achieve the room set point.
- Due to the increasing room temperatures and humidity, occupant behaviour starts reacting on more cooling demand thus lowering the room set points. This change in set point allows the system to work for higher periods.
- These operational faults yield in higher power consumption, a set of performance indicators for assessing the performance of maintenance procedures can be used as a tool to assess the impacts of common operation and maintenance faults on HVAC performance, and improve the integration of HVAC systems operations into the overall building maintainability (BM).

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