Journal of Mechanical Engineering *Vol 19(2), 219-232, 2022*

Application of Variable Speed Drive to Overcome Air Conditioning Oversizing Issue

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ABSTRACT

This paper was aimed at studying the impact of a variable speed drive in tackling the issue caused by an oversized air conditioning system. In this study, oversizing was determined by calculating the actual load demand in an operating air handling unit (AHU), and the formation of mould growth as an indicator of the failure of the AHU to dehumidify the air. A comparison was made between the performance of an actual operating AHU, the performance of the AHU after the installation of a variable speed drive (VSD), and an appropriately sized simulated model of a building using building energy simulation software. The study found that the installed AHU was oversized by 60% and that the installation of VSD is effective in reducing the effective total capacity to meet actual cooling load demand. This study also shows that VSD installation successfully eliminates favourable condition of mould growth by simultaneously reducing AHU capacity and room relative humidity. However, VSD installation should not be standard practice in lieu of proper calculations to determine the appropriate size for an air conditioning system. The simulation result shows that correctly sized air conditioning system will be able to maintain ideal room condition without incurring energy penalties associated with oversizing.

Keywords: *Oversizing; Air Conditioning; VSD; Computational*

ISSN 1823-5514, eISSN 2550-164X
Received for review: 2020-09-05
Accepted for publication: 2021-10-10
Published: 2022-04-15

Introduction

According to Energy Commission of Malaysia, the building sector, which includes residential and commercial properties, accounted for 12.5% of the total energy consumption and 50.5% of the total electricity consumption of Malaysia in 2017 [1]. With the construction industry projected to grow by 7-8% annually, it is safe to assume that energy consumption will steadily increase in the future. Out of all the energy used in a building, 49% of it is consumed by air conditioning systems, according to a study commissioned by the Danish International Development Agency [2]. Globally, air conditioning demand is steadily increasing at an annual rate of 6.2% [3]. This shows that it is an important area to analyse in order to avoid any energy wastage in commercial buildings.

Notwithstanding that, there is tendency among air conditioning system industry practitioners to over-design and over-specify. In an engineering system context, overdesign is defined as excess or surplus in a system once the necessities of the systems are met [4]. Research by Felts and Bailey [5] indicated that of the of the 250-installation studied, 20% of its installed air conditioner is oversized by 25% or less, 40% oversized by more than 25% in which 10% are oversized by more than 50%. Another study by Djunaedy et al. [6] that studies oversizing by measuring cycling rate suggest that it is not uncommon for air conditioning system to be oversized by as much as 100%. A more recent and wider research by Jones and Eckert across various air conditioning components including water cooled chiller, air cooled direct expansion unit, distribution pump and ventilation supports this finding by showing an average oversizing factor that range from 1.5 to 3 [7]. Eckert and Isaksson attributed this practice to overdesign to the need to provide flexibilities, increase resilience, eliminate uncertainties and mitigate the risks associated with flawed calculations, especially with regard to unspecified parameters such as occupancy level, infiltration and lighting intensity [8]. Proctor et al. [9], on the other hand, reported on the perception among industry customers that a bigger capacity is always better. Overdesign not only happens in new projects where calculation is based on estimated quantities but also regrettably repeated in retrofitted projects where energy need, and equipment's performance is readily available. A recent study by Jones et al. [10] among five hospital organisations which recently replaces their air conditioning system shows that overdesign still happens due to failure to properly collect current and future energy needs and to accurately assess required energy safety margins.

Unfortunately, the oversizing of an air conditioning system brings adverse unintended consequences in multiple aspects. A study by McLain et al. [11] for example, showed that an average oversized air conditioner consumes 10% more energy. Another study by Henderson supported McLain's findings and added that more energy is wasted when the degree of oversizing is higher [12]. James et al. collected data on 368 homes and found increases of energy of between 3.7% to 9.3% with oversized capacities of between 20% to 50% [13]. In Australia, Thomas and Moller [14] found that an oversized chiller plant incurs 30% additional capital cost while also adding 4.3% to the operational cost. The problem of oversizing cost approximately £224 billion globally originated from more expensive and underperforming system [15]. Any potential benefit gained from shorter cooling run time was outweighed by the efficiency loss due to increased cycling need of oversized unit. Oversizing not only cost more to build, but it also incurs recurring operational cost penalties to the building owners.

Aside from energy, oversizing also reduces the comfort level by affecting the effectiveness of the system to dehumidify incoming air and control room humidity. Shirey et al. [16] found that a system that operates at less than 50% capacity typically does not provide any latent effect. Winkler et al. [17] finds that this is more apparent at high humidity climate where oversized air conditioning system holds higher fraction of latent load. This clearly shows the drawback of an oversized system since it spends more time in a partial load condition compared to a proper-sized system. Air that is insufficiently dehumidified will raise the relative humidity inside a room and subsequently creates a conducive environment for mould growth [18]. According to Yau and Ng [19], mould growth in a room is exacerbated when the cooling coil in an air conditioning system fails to remove the air moisture content to below 70% of the relative humidity.

Mould growth is highly undesirable since it creates odour problems and is very hazardous to human health. Air conditioning system components itself provides conducive breeding ground as reported by Prezant et al. [20] where mold is easily found in filters, insulation and drain pan. When mould comes into contact with foam insulation, fungal degradation will cause it to release urea formaldehyde, which has an unpleasant smell and gives rise to other problematic symptoms such as headache, nasal irritation, dizziness, fatigue and nausea [21]. Khan and Karuppayil [22] stated that among other health hazards caused by mould are respiratory symptoms, such as the common cold, due to inflammation of the nasal sinus, hypersensitivity syndrome that can result in pneumonia-like symptoms due to exposure and sensitization of mould inhalation, respiratory infection, especially in immunocompromised individuals, rheumatologic and other immune diseases due to inflammation and stiffness in muscles or tissues, allergies, which cause diseases such as asthma, rhinitis, sinusitis, pulmonary mycoses and hypersensitivity pneumonitis, and neuro-psychiatric problems such as cognitive defects and difficulties in concentration. Thus, any sighting of mould in a building should raise concerns and be acted upon, especially in vulnerable places such as hospitals.

Background and Methodology

A department in a newly constructed hospital building in Klang, Selangor was severely infected by mould, which raised serious health concerns among its occupants. Mould growth was clearly visible on the walls, ceiling and, in certain cases, even inside the air handling unit (AHU) of the air conditioning system. Table 1 shows the parameters of installed AHU at the hospital. The affected department was fully air-conditioned for 24 hours at a set temperature of 24 °C. The air conditioner used a dedicated centralized chilled AHU, with the incoming and outgoing chilled water temperature set at 6.7 °C and 12.2 °C, respectively. The initial room data recorded by a data logger showed favourable conditions for mould growth, with the average temperature and relative humidity recorded at 22 °C and 83.3%, respectively.

Table 1: Parameters of installed AHU

AHU Parameters	**Value**
Total Load (Btu/Hr)	493,375
Airflow (CFM)	14,300
Water Flow Rate (USGPM)	99
Air-Conditioned Area (ft^2)	9,159

Several efforts were made to reduce the possible causes of mould to no noticeable effect. For example, all the unwanted fresh air openings that might have caused unnecessary infiltration were closed, and all the other water-carrying services were checked and confirmed to be without any leakage. In the absence of any external source of moisture, the data clearly showed that the air conditioning system was incapable of achieving the conditions recommended by the MS1525: Code of Practice on Energy Efficiency and Use of Renewable Energy for Non-Residential Buildings, which states that the relative humidity inside a building should be between 55% to 70%. Another method to eliminate potential equipment error was to constantly open the modulating valve of the AHU. This was done to allow the chilled water to continue circulating inside the cooling coil of the AHU to maintain the dew point temperature of the apparatus and to ensure that the dehumidification process occurred all the time.

To study the capacity of the air conditioning system and its impact on mould growth, the AHU parameters were compared to the recommended figures of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), as provided in the ASHRAE Handbook – Fundamental. The actual heat load transferred in the AHU was then calculated using the following equation:

$$\text{Total Load (Q)} = 4.5 \times \text{Airflow (CFM)} \times \Delta \text{ Enthalpy (btu/lb)} \qquad (1)$$

The delta enthalpy was obtained by recording the supply of air, the mixing air temperature and the relative humidity in the AHU and converting them by means of a psychrometric chart. The total load calculated was then compared to the actual load of the AHU installed at the site.

Theoretically, the best way to tackle any problem with regard to oversized air conditioning is by replacing the existing unit with a smaller unit that is sized according to its actual operating capacity. However, this method is unfavourable for operating in a building since the operating hours need to be suspended and a significant amount of money has to be allocated for a replacement unit. A more economical and time saving solution is by supplementing the existing AHU with a variable speed drive (VSD) unit. While VSD units have largely been used in the industry to save energy, their working mechanism also theoretically enables them to reduce the capacities of AHUs. The VSD slows down the motor frequency which, in turn, reduces the fan speed. This reduction in the fan speed will directly reduce the airflow and consequently, the overall total load capacity of the AHU. The effects of the VSD on the room temperature, relative humidity and total load capacity of the AHU were recorded for comparison.

Another method adopted for making a comparison was by using a building simulation software to calculate and observe the impact of an air conditioning system that had been optimized for use by the hospital. A building simulation software was preferred over other traditional methods such as rule-of-thumb or spreadsheet-based calculations due to its ability to process a huge number of variables and considerations in order to present more accurate results. It also has the added advantage of having a greater flexibility in determining its design conditions and its subsequent impact on the resulting parameters.

The building simulation software used for the analysis was the Integrated Environmental Solutions IES-VE 2017. Based on Figure 1, the simulation process started first with the preparation of the building model, which resembled the actual hospital building as closely as possible as demonstrated in Figure 2. Next, the parameters that influenced the transfer of heat to the building were inserted, including the ambient conditions, properties of the building fabric, operational hours, and internal and external thermal sources as shown in Table 2. Next, the components of the air conditioning system for the building model were selected and programmed to reflect the actual operating conditions. Once all the inputs were in place, the simulation calculated the room, system and plant heat load before displaying the results for analysis.

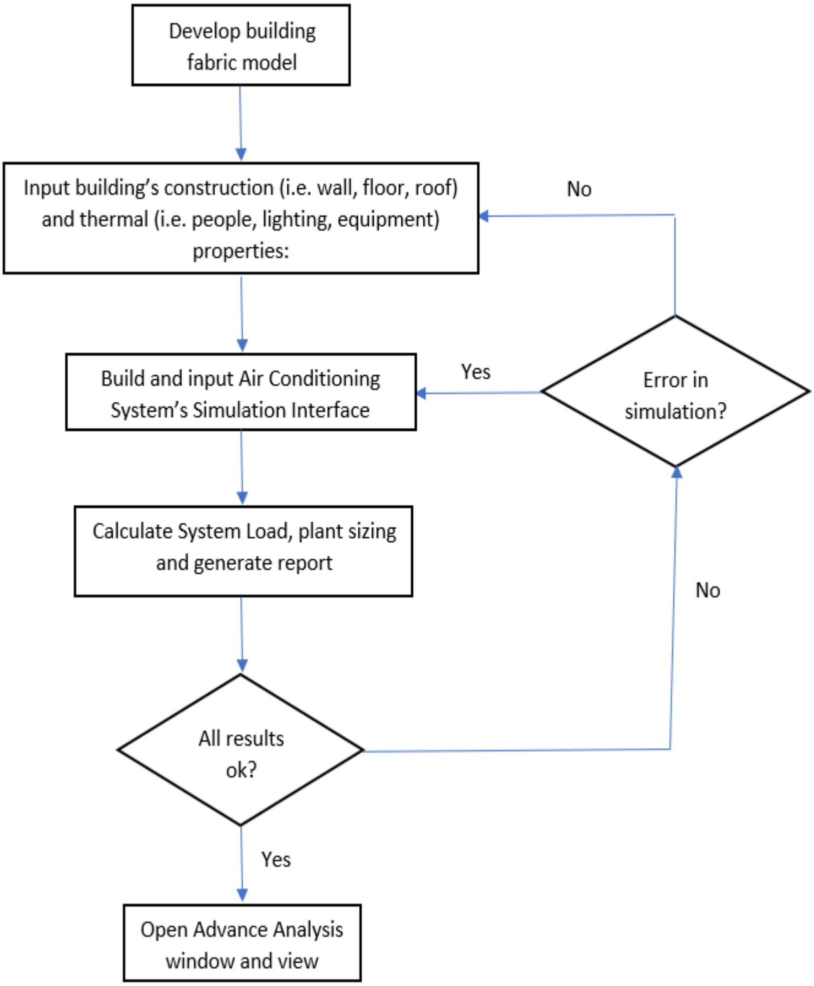

Figure 1: IES-VE 2017 simulation process

Table 2: IES-VE 2017 simulation settings

Component		Setting
Building Envelope	Area	1,860 ft^2
	Wall	0.4 Btu/hr/ft^2/°F
	Window	1.2 Btu/hr/ft^2/°F
	Floor	0.25 Btu/hr/ft^2/°F
Internal Heat Source	People	40 people
	Lighting	2 W/ft^2
	Equipment	0.5 W/ft^2
Air Conditioning System Components	1. Fan 2. Cooling Coil 3. Ducting 4. Chilled Water from Chiller	

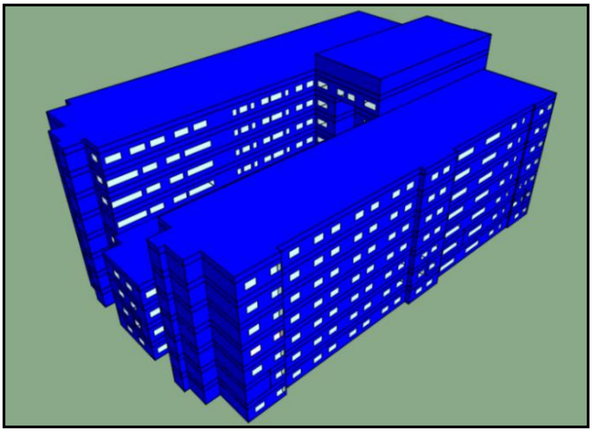

Figure 2: IES-VE 2017 building model

Results and Discussion

From the gathered data shown in Figure 3, the average temperature and relative humidity of the affected area were 22.3 °C and 80.6%, respectively, which were within the favourable range for mould growth [19]. The impact on the temperature and relative humidity after the implementation of efforts to improve the situation by closing all the air openings and the modulating valve of the AHU is shown in Table 3 below:

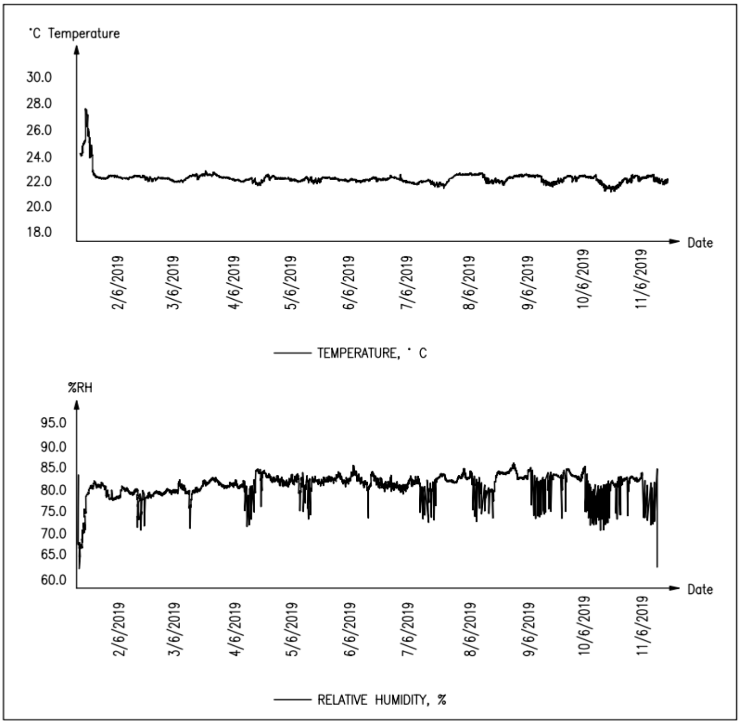

Figure 3: Original temperature and relative humidity profile

Table 3: Average recorded temperature and relative humidity

Situation	Temperature (°C)	Relative Humidity (%)
Normal	22.3	80.6
A: Closed fresh air openings	22.7	77.12
B: Opening modulating valve	21.8	74.14

The relative humidity profile clearly showed that the AHU was incapable of effectively dehumidifying the incoming air as similarly explained in [16]. The room temperature profile supported this observation, where it showed that the temperature rose and fell within a short period of time. On the other hand, the relative humidity remained elevated, even though the room temperature was kept consistently low. A low relative humidity was only observed to have occurred swiftly and intermittently. In addition, the temperature and relative humidity profiles showed that there was constant cycling in short time intervals [6]. The start-up period, during which the AHU first cooled the room from ambient temperature to the intended room temperature only took approximately 30 minutes. This indicated that the AHU only required a short time to achieve the required room temperature before active heat transfer at the cooling coil was stopped by closing the modulating valve of the AHU. The absence of chilled water inside the cooling coil increased the dew point temperature of the coil apparatus and reduced its condensation ability, which resulted in the room having a high relative humidity. The high temperature in the coil caused the moisture at the coil to evaporate back into the air that was being supplied to the room. Furthermore, the AHU was designed so that more than 80% of the supplied air would be recycled. Thus, the returning air at a sufficiently low temperature would further invalidate the need for a cooling coil to dehumidify the air. The pattern of constant cycling and a consistently high relative humidity in the room during operating hours showed that the size of the existing cooling coil did not match the load requirement of the building, and thus, failed to dehumidify the incoming air [18].

The initiative to improve the performance of the AHU showed that closing the fresh air openings only resulted in marginal improvements to the situation. On the other hand, opening the modulating valve gave a better improvement in terms of reducing the relative humidity. However, it had the unintended effect of reducing the room temperature instead. This was because the constant opening of the modulating valve ensured that the temperature of the cooling coil in the AHU remained artificially low, even when the room temperature had long met its objective. Energy was also wasted in this method since the heat transfer continued to take place and therefore, it had to be compensated by a cooling process powered by a water-cooled chiller, cooling tower and pumps.

In terms of size, the load capacity of the AHU at 53.9 Btu/hr-ft^2 for the air-conditioned area was well within the recommended value in the ASHRAE Pocket Guide for Air Conditioning, Heating, Ventilation, Refrigeration [23]. This recommended value, however, should not be taken at face value given that it does not take into account differences in the geographical location, operating hours, weather conditions, quality of building materials, and the actual internal and external loads of the building. The nonstop operating hours in a hospital department, for example, require a lower AHU capacity since its constant operation eliminates the need for a starting load factor. A hospital building also has more air-conditioned zones adjacent to each other, which would reduce the overall ratio of heat transfer between the air conditioned and non-air-conditioned areas. The actual total load capacity of the AHU that was calculated using actual data was 203,346 Btu/hr, which was 58% lower than the installed capacity of 493,375 Btu/hr. A comparison between the parameters of the installed, VSD-installed and simulated AHUs is shown in the table and figure below:

Table 4: Comparison of AHU data and performance

Description	**Original**	**VSD-Installed**	**Simulation**
AHU Capacity (Btu/hr)	493,375	208,800	236,620
Fan Airflow (CFM)	14,300	8,500	9,770
Cooling per area (Btuh/ft^2)	53.9	22.8	25.9
On Coil Dry Bulb Temperature (°C)	20.9	21.8	27
Off Coil Dry Bulb Temperature (°C)	16.6	14.1	15.5
Room Temperature (°C)	22	22.5	22.7
Room Relative Humidity (%)	78.9	55.9	56.5
Electrical Input (Amp)	29	9.2	6.9

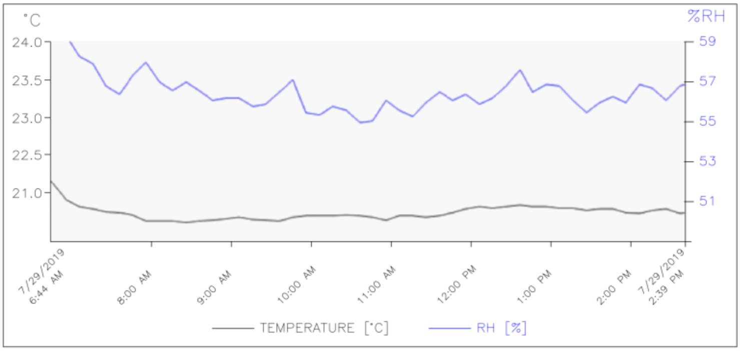

Figure 4: Room temperature and relative humidity after installation of VSD

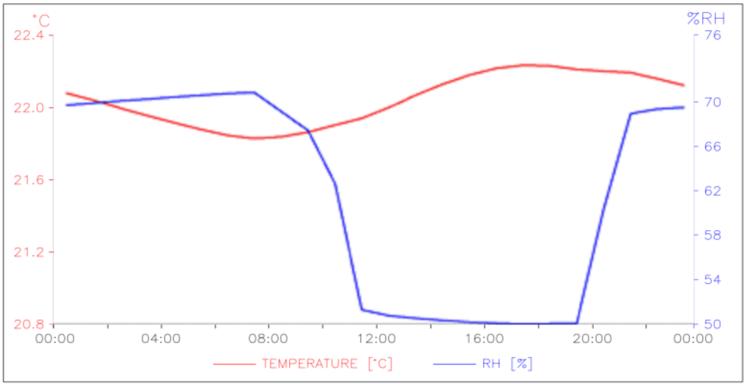

Figure 5: Simulated temperature and relative humidity profiles

From the information above, the cooling load calculation performed by the building simulation software closely resembled the performance of the actual AHU after the installation of the VSD. An appropriately sized AHU will be able to sufficiently dehumidify the incoming air while achieving the desired room temperature. It will also consume the least amount of energy since the AHU will be able to run at the optimum running efficiency of its fan and motor.

The initiative to tackle a high relative humidity caused by an oversized AHU by installing a VSD showed positive results. As the frequency was reduced, the relative humidity of the room also fell. At 30 Hz, the relative humidity of the room was no longer favourable for mould growth because the lower frequency resulted in a lower airflow and fan speed. As a result, the lower air volume at a slower speed allowed the cooling coil apparatus of the AHU to maintain a dew point temperature and to sufficiently dehumidify the incoming air before it was delivered into the room. Overall, the data recorded after the installation of the VSD showed that the capacity of the AHU was reduced by 60% to become closer to the actual building load at 208,880 Btu/hr. The addition of the VSD also had the added advantage of lowering the energy consumption. Based on the fan affinity law, the lower fan speed (n) reduced the need for a high-power input (P) by multiple factors.

$$P_1 / P_2 = (n_1 / n_2)^3 \tag{2}$$

However, the recorded electrical energy required for the AHU with an installed VSD was higher than the calculated and simulated results, albeit with a higher-capacity fan used in the simulation. This was because the motor efficiency dropped as the VSD was used to reduce the motor speed. Although the overall energy consumption was reduced, it was not optimized to its designed specification. In general, the performance of the AHU after the installation of the VSD was consistent with its theoretical performance that was simulated using the IESVE.

Conclusion

In conclusion, this study showed that an oversized air conditioner will lead to unnecessary energy wastage and higher power consumption. The installed AHU's oversized capacity of more than 100% is in line with study conducted by Djunaedy et al. previously [6]. This increased capacity inevitably leads to higher operational cost because of higher energy consumption as similarly reported in previous studies [11,12,13,14]. This is due to the mismatch between the installed air conditioner and its actual need. As only a blower fan was used in the study, the energy saving for the whole air conditioning system should be higher once savings from other energy-intensive equipment such as chillers, pumps and cooling towers are considered. The simulation also showed that oversizing degrades the dehumidification capability, thereby raising the relative humidity of a room [16]. Most air conditioning systems set only the dry bulb temperature as the objective and chilled water flow as the control variable. This chilled water is controlled by a modulating valve that opens during the cooling process and shuts once the dry bulb temperature in the room is met. Unfortunately, it does not necessarily lead to sufficient dehumidification of the incoming air. As shown in the measured data, the constant opening and closing of the motorized valve resulted in elevated and cyclical relative humidity of the room. Failure to maintain a consistently low relative humidity inevitably invites the risk of mould growth.

The introduction of a VSD, as shown in this study, successfully reduced the capacity of the AHU and the relative humidity. The hospital should be mould-free once all the mould spores are cleaned and removed from its environment. However, this method should not be used consistently because the energy is not optimized due to reduced motor efficiency when the VSD is applied. As shown in the simulation, a properly designed air conditioning system should be sufficient to meet its actual needs. It should also be able to allow all its components to run at their optimal operating condition. Without incurring an energy penalty associated with the VSD, the overall air conditioning system will consume less energy. Oversizing an air conditioning system to eliminate uncertainties should never be practised since its unintended consequences will adversely impact not only the finance but also public health.

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