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Alternative Strategies to Central Heating Ventilation and Air Conditioning

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Abstract: Central heating, ventilation and air conditioning (HVAC) is one of the largest consumers of energy in the residential sector. This project explores the use of multiple HVAC units and/or Zoning in a single residence to reduce energy loads. The energy consumption data of a detached single-family home using two HVAC units, one primary for the main house and a secondary HVAC for a casita, was collected for the same month for two consecutive years, along with details related to the outdoor temperature and the square footage being air-conditioned by each HVAC. A regression algorithm was trained using the above details to find the relation between the parameters. Next, based on the occupancy and usage patterns, the HVAC was redesigned assuming more area under the secondary HVAC unit. The trained algorithm was then used to make energy usage predictions for the revised primary HVAC area, with the assumption that the secondary HVAC unit was turned off. The results were compared with existing energy usage data. It was determined that there were significant energy savings in the second scenario. It is expected that this study and its findings will help future research projects explore more ideas as alternatives to central HVAC, in improving the economic viability of existing options, and in developing a savings calculation tool that will help consumers make informed decisions on their best alternatives to central HVAC.

Key words: HVAC, residential building, energy use, economic viability

1. INTRODUCTION

Now more than ever, it is important to reduce energy consumption and move towards sustainability. While this is a widely accepted ideology today, some means for energy reduction such as using solar energy are more popular and well explored than others, such as zoning/multiple HVACs for a single-family home. Detached single-family homes were chosen for the study as they hold the largest share in the residential sector by home type [1]. Fig. 1 shows that 54% of the total energy consumption in a detached single-family home is used for space heating and air-conditioning [2]. In addition, it has be seen from Fig. 2, that there has been a constant rise in the number of homes fitted with central AC.

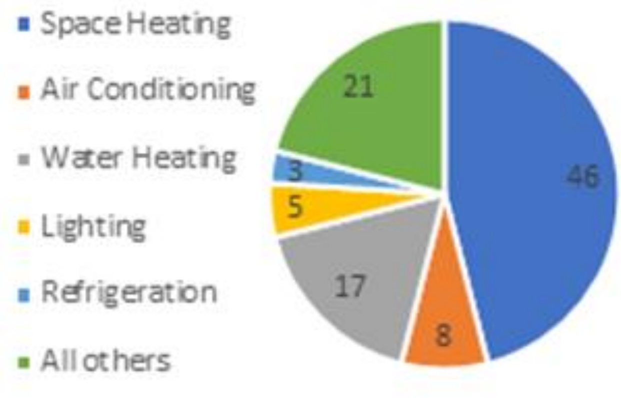

Figure 1. End-use consumption shared by single-family homes. (eia.gov, 2015)

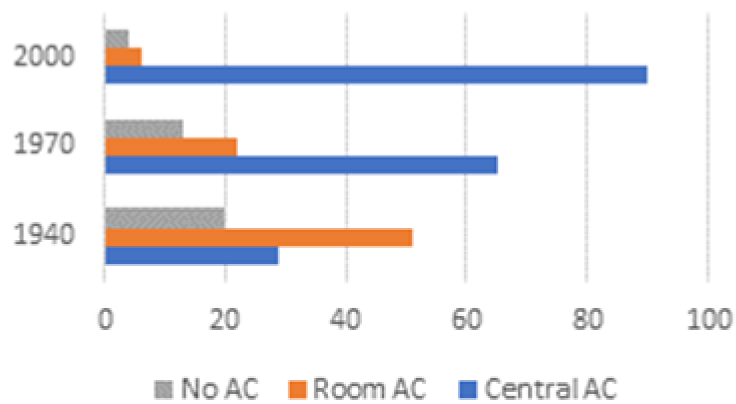

Figure 2. Rise in AC in new home. (Source: eia.gov, 2015)

A crucial point to note is that much of the energy spent on home conditioning is on spaces that are not used often. The average single-family home in 2019 was at 2,301 square feet, which is an increase of nearly 660 square feet in the last 40 years [3]. In contrast, the average number of people has decreased from 3.01 persons per household 50 years ago to 2.54 today [1]. As seen in Fig. 3, the average family spends about 68% of their time in concentrated areas like the kitchen, nook, and family room, which account for approximately 30.5% of a home's floor area [4].

Figure 3. Usage pattern of an average family based on time spent in the spaces.

From all the above-mentioned information, it can be inferred that there is a critical need to rethink HVAC system design. As a step towards this, this project studies the impact of zoning a central HVAC system, or using multiple HVAC systems, to condition spaces. Showing potential energy savings could make a strong case for promoting these alternate systems, and could lead to huge energy savings, benefitting both the consumer and the environment. This could also help future research projects exploring more ideas as alternatives to central HVAC, as well as improving the feasibility of existing studies based on their installation costs versus savings.

There are various ways to zone a home, with the general concept being to segregate spaces based on owners' use/requirements, and each zone can be regulated independently (even on a single HVAC system). This not only increases the occupants' thermal comfort but is also an efficient way to achieve energy savings. The driving factor for any HVAC alternate to be widely used in the market is their economic viability and benefits.

2. LITERATURE REVIEW

Researchers have been exploring various approaches to HVAC energy reduction. Efforts are being made to increase the efficiency of HVAC systems – ductless air-conditioning systems are being promoted, newer HVAC systems have higher efficiency ratings now, and systems with low GFC refrigerants are bring introduced. Smart thermostats are also a way to achieve some energy savings [5]. However, these methods still leave scope for significant energy savings that can be achieved by completely shutting off HVAC systems, or setting them at significantly different temperatures.

Though not common, zoning a new home's HVAC has been done for a while. A Mitsubishi Electric case study estimated as much as 75% savings for a 10,000 square foot home in 2008 [6]. For a wider reach, zoning an existing HVAC system by retrofitting it is being studied in various ways, including some that involve installing additional devices, like cameras, tagging etc., as well as some others that are working to avoid such additional installations for an easier retrofit to make them more marketable [7]. While these studies investigate increasing thermal comfort and possible energy reduction, they do not assess the possible savings that can be achieved by using the systems. Some studies mention energy savings by owners using zoning methods, but there is no clear connection established between the area (size) zoned, zoning method, or savings percentage (ZoneFirst, Pdf).

3. METHODOLOGY

For this study, one detached single-family home using two HVAC units was selected. Fig. 4 graphically represents the research methodology steps. Combined energy usage data was gathered from the energy bills for the month of August consecutively for two years: one year when only the primary HVAC was running, and the next year when both the primary and secondary HVACs were in use and set at the same temperature. In addition, the area each unit served was noted, along with the daily outdoor temperatures for the month. The energy usage for both years was mapped, with respect to the square footage being conditioned and the outdoor temperature. Linear regression was used to compare and determine the relationships between the variables of area, temperature, and energy consumption.

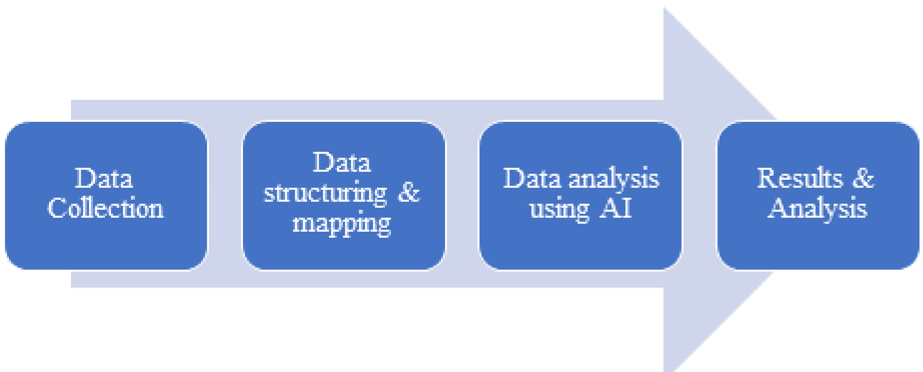

Figure 4. Research methodology steps

In the next step, the home's HVAC system was redesigned, and less frequently used spaces were added under a secondary HVAC unit. The derived linear regression equation was used to make new energy usage predictions for the scenario in which the primary HVAC unit was serving reduced energy and the secondary HVAC unit was turned off. Using a program in Python, a new energy usage dataset was then compared to the previous data from when the primary HVAC was serving a larger square footage area of the home (year one data). The program checked for reductions in energy consumption if any, and in case or reduction, the percentage of energy savings was also calculated. The results were analyzed, and based on the results, possible applications of this study are discussed.

4. CASE STUDY PROJECT RESULTS

The home's monthly energy usage was gathered, as detailed in the research methodology. Some minor adjustments were made to the data to adjust for appliances that were replaced after the first year. The adjusted data was tabulated and plotted in Python, as shown in Fig. 5, to compare the energy consumption. From the plot, it is evident that the energy consumption was higher when both HVAC units are running, as expected.

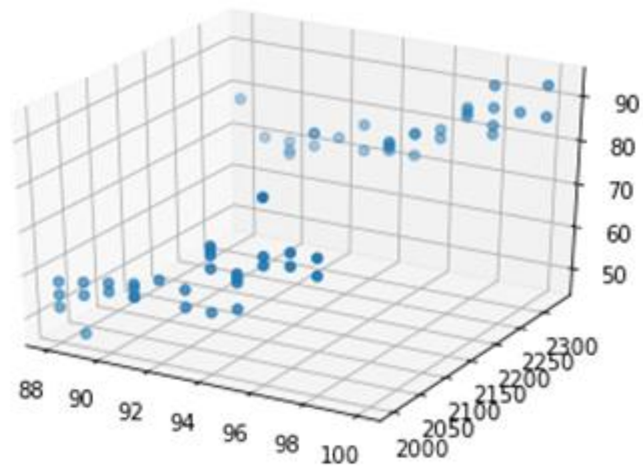

Figure 5. Energy consumption comparison

Fig. 6 shows the residence's layout, as well as the hatch area that measures 330 sq. ft., and represents the area air-conditioned by the secondary HVAC, along with the rest of the 2000 sq. ft. house that runs on the primary HVAC. After studying the residence's occupancy patterns, for the purpose of energy simulation, two bedrooms that were less frequently used were added to the secondary HVAC unit, as seen in Fig. 7. The assumption was that the secondary HVAC unit would not run as often as the primary unit. Hence, the addition of these spaces would reduce load on the primary unit that ran most of the time. The new area being air-conditioned by the secondary HVAC increased to 636. sq. ft., and the area under the primary HVAC decreased to 1694 sq. ft.

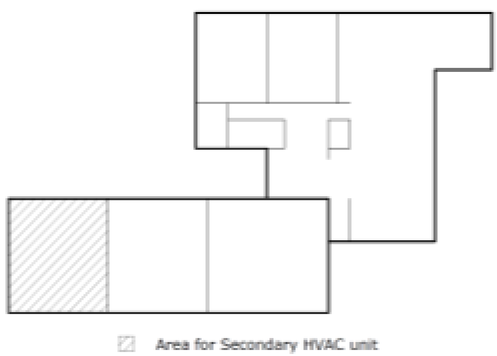

Figure 6. Existing area on secondary HVAC

Figure 7. Area on secondary HVAC for simulation

Data simulation using Artificial Intelligence in Python

Table 1 shows the sample tabulation of the daily energy consumption data collected for August 2019. The entire dataset was input in Python as a single table. Linear regression between the parameters was derived and then used to predict energy consumption for the revised data.

Table 1. Daily energy consumption in KWh

Area of Residence Air Conditioned	Average Temp (F)	Energy consumed (KWh)

2000sqft	90.07	57.93
2000sqft	95.09	65.56
2000sqft	96.60	71.50
2000sqft	97.54	74.77
2000sqft	98.29	70.53
2000sqft	95.00	60.41
2000sqft	88.83	46.86
2000sqft	87.69	55.06
2000sqft	91.05	57.67

The data simulation for the reduced area under the primary HVAC showed a clear decrease in the energy consumption, as expected. Of the 62 predictions made, all except one yielded energy savings. The percentage of average savings calculated was 19.65%. The key finding of this study is that only a 15% decrease in the area under the primary HVAC led to an energy savings of almost 20%. For an average US household, this would lead to a savings of 2195 Kwh, or approximately $300 [2]. In other words, 4850 pounds of CO_2 emission savings per household per year can be achieved for coal generated electricity [8]. Even if a small percentage of the households using HVAC make a shift towards zoning, it could lead to huge energy savings and environmental benefits. This method could be combined with other methods, like Energy-star rated HVAC systems, smart thermostats, etc., for even more energy savings.

5. CONCLUSIONS

The study can be used to simulate multiple zoning scenarios to design the most efficient zoning system. Simulations can be conducted for different scenarios, and a home's most suitable zoning pattern can be determined. The study can also be used to select the most relevant zoning system under given circumstances. A savings calculator can be developed based on the study methodology to help consumers choose the best alternate. For example, a HVAC room zoning retrofit those costs about $3000/room might not be a viable choice for a homeowner who saves $300 annually, since just the breakeven time would be 10 years, and the owners might not intend to stay in that home for that duration of time. Therefore, a $200 smart vent might be a more viable option for such a homeowner. Simulations can also be used for future research to determine other ways of zoning or improving existing zoning technology to be more cost effective.

Zoning a building/residence involves many more steps than determining the occupancy rate and usage patterns of the owners/occupants. The solar exposure, equipment, age, and construction type, lighting, and ventilation load, etc, all must be considered for it to be a thorough and successful zoning that can maintain thermal comfort and reduce energy. Moreover, in terms of the algorithm used to study and predict data, its accuracy depends on the amount of training data used. Due to the project type and time restrictions, limited data was used to train the algorithm used in this study. The results could vary when a larger dataset is used, and the percentage of anticipated savings could also vary significantly. In addition, the efficiency of different HVAC systems was not considered when calculating the energy savings.

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