DEVELOPMENT OF AN INTEGRATED AIR HANDLING SYSTEM FOR LARGE COMMERCIAL BUILDINGS

By

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Development of an Integrated Air Handling System for Large Commercial Buildings

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Commercial building energy consumption has increased from 3,661 trillion BTUs in 1949 to 17,397 trillion BTUs in 2002. HVAC systems in large commercial buildings consume about half of the total energy. The energy used by HVAC systems is in excess of the sum total of the building loads. Excess energy usage is primarily caused by simultaneous cooling and heating systems. As one solution to this problem, an all-air AHU system for large commercial building, named Integrated Office Air Hanlding Unit (OAHU) system, has been developed in this study. This dissertation covers:

Description of the new system: A summary of conventional AHU systems for large commercial buildings, and the advantages and disadvantages of conventional systems as found in a literature review, is presented. A new all-air system is designed with the following three features: 1) the system transfers interior zone heat gains to the exterior zone; 2) the system separates interior zone supply air from the exterior zone supply air; and 3) the new system decouples latent and sensible cooling.

Development of system optimal operation schedule: The OAHU system can introduce outside air into the building through either the interior zone or the exterior zone outside air duct, or both. The benefit of the OAHU system is the flexibility of the outside air intake. To minimize energy consumption with an acceptable or improved IAQ, the

optimal outside air intake schedule is achieved using the objective function of the energy consumption.

Evaluation of OAHU system energy performance: Analytical energy consumption models have been developed for the OAHU system and two conventional all-air AHU systems. Energy performance is compared between the OAHU system and two conventional AHU systems.

Implementation of the system: Two case buildings are studied. The effectiveness of the system is measured by projecting the potential thermal savings, estimating the system retrofit, and conducting a cost analysis.

Conclusion of the research: The study has showed that the OAHU system is a cost-effective way to reduce or eliminate simultaneous cooling and heating consumption to improve energy system performance of large commercial buildings. Suggestions for future work, based on this research, are proposed.

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Nomenclature

β	= Outside air intake ratio
c	= CO_2 concentration
ζ	= Return air from the interior zone to the exterior zone
φ	= Interior airflow rate over total airflow rate
δ	= Common exhaust air flow ratio from the interior zone
m	= Airflow mass rate (kg/s or lbm/hr)
ξ	= Direct relief air flow ratio from the interior zone
Cp	= Specific heat for dry air (kJ/(kg·°C) or Btu/(lbm·°F))
e	= Specific energy consumption (kJ/kg or Btu/ lbm)
Δe	= Specific energy savings (kJ/kg or Btu/ lbm)
E	= Energy consumption (kJ or Btu)
h	= Air enthalpy (kJ/kg or Btu/lbm)
T	= Air temperature (°C or °F)
Rh	= Relative humidity
α	= Air flow ratio for VAV system
γ	= Exterior zone load ratio
q	= Heating or cooling load

Subscripts

a	= Simulation parameter and results in Figure 4 with some assumptions

b = Base case systems, single unit systems

c = Cold deck temperature set point

cc = Cooling

cr = Critical number

d = Design condition

dew = Dew point temperature

e = Exterior zone

eco = Economizer

esl = Economizer starting line

h = Heating energy consumption

i = Interior zone

IAQ = Indoor air quality

mix = Mixed air

min = Minimum

o = Optimal solution

oa = Outside air

rh = Reheat heating

r = Return air or room air condition

s = Supply air

set = Minimum design value

Superscripts

b = Base case system (the SAHU or TAHU system)

Chapter 1: Introduction

According to the Annual Energy Review published by the Energy Information Administration (EIA), commercial building energy consumption in the United States has increased from 3,661 trillion BTUs in 1949 to 17,397 trillion BTUs in 2002 [1]. HVAC systems in large commercial buildings account for almost half of the total energy consumption. The energy consumed by HVAC systems is in excess of the sum total of the building loads [2]. Reducing the cost of building energy system operations has been the goal of many HVAC design and operation analysis efforts [3].

A single air-handling unit in an HVAC system has to provide conditioned air at a low humidity ratio and different supply temperatures to multiple zones in a building. But it can do so only by resorting to (a) low cold deck air temperature and (b) a certain amount of mixing of cold and hot air stream in dual-duct systems, or terminal reheating as in single-duct systems. Energy delivery efficiency, or EDE, was developed to rate the energy performance of HVAC systems on an absolute scale. The study [4] found that the energy consumption of typical existing systems is twice as high as the sum of the heating and cooling loads even when the systems are operated using optimized schedules [5]. However, the energy performance of HVAC systems can be improved significantly by introducing a new type of AHU system.

Large commercial buildings have multiple zones, which can be categorized into interior zones and exterior zones. The exterior zone is directly affected by weather conditions. It has cooling loads in the summer and heating loads in the winter. The interior zone, on the other hand, is only affected by internal heat gains. It needs cooling year round. There exists a significant energy conservation potential for large commercial

buildings when the internal heat generated by the interior zone is transferred to the exterior zone and used as a heat supply. To achieve this goal, this study has developed an innovative all-air air-handling unit called the Integrated Office Air-Handling Unit (OAHU) system.

This study focuses on developing an optimal operation schedule for the OAHU system, estimating its energy performance and conducting comparative economic analyses. In Chapter 2, the research background is discussed. Based on a literature review, four types of conventional air-handling units are introduced. The advantages and disadvantages of the conventional systems are compared with respect to energy conservation features that the OAHU system should have.

Chapter 3 introduces the OAHU system: The configuration and features of the OAHU system are presented. In Chapter 4, optimization of the OAHU system operations is discussed: An Indoor Air Quality (IAQ) model is built to analyze the specific minimum outside air requirements for the OAHU system. Optimal outside air intake schedules, which are optimal solutions of a two-dimensional linear objective function with non-linear constraints, are developed by using a geometric method.

An analysis of the energy performance of the OAHU system compared with the single air-handling unit SAHU is given in Chapter 5: First, an optimal baseline operation of the SAHU system is presented. A theoretical analysis is then conducted to compare the energy consumption of both systems. A two-step simulation is conducted to demonstrate the energy savings of the OAHU system over the SAHU system using quantitative measures.

Chapter 6 presents an analysis of the OAHU energy performance compared with the two-dedicated air-handling unit (TAHU). An optimal baseline operation of the TAHU system is first presented. A theoretical analysis is conducted to compare the energy consumption. A two-step simulation demonstrates the energy savings of the OAHU system over the TAHU system.

The annual energy savings of the OAHU system are presented in Chapter 7: The annual savings in three typical cities are calculated based on weather bin data using the models developed in Chapter 5 and 6. The three cities are San Antonio, Los Angeles and Minneapolis, which represent humid, dry and cold weather conditions respectively.

Chapter 8 presents an economic analysis using case study buildings. Two actual buildings are chosen to conduct the economic analysis. Annual savings is estimated based on the actual system operations using 8760 hourly weather data. Simple paybacks are also projected. Finally, Chapter 9 concludes this study and gives recommendations for future work based on this research.

[References]

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Chapter 2: Research background

Over the years, several kinds of air-handling units (AHUs) have been developed for large commercial buildings for energy conservation purposes. This chapter introduces the history of this development, compares several types of all-air AHU systems and air-and-water systems, and presents the advantages and disadvantages of conventional AHUs. In addition, the expected features of the OAHU system are summarized.

2.1 The single air handling unit (SAHU)

The single air handling system (SAHU) is defined as one single duct system with cooling and heating coils in a series flow air path that serve both the interior and exterior zones. Figure 2-1 presents the system configuration. The SAHU system provides complete sensible heating and humidification and sensible and latent cooling by supplying air to the conditioned space. In such a system, no additional cooling is required in conditioned zones. The discharge air temperature is maintained at a fixed cold air temperature by a cooling coil valve, heating coil valve and outside air and return air damper controls during the economizer control period.

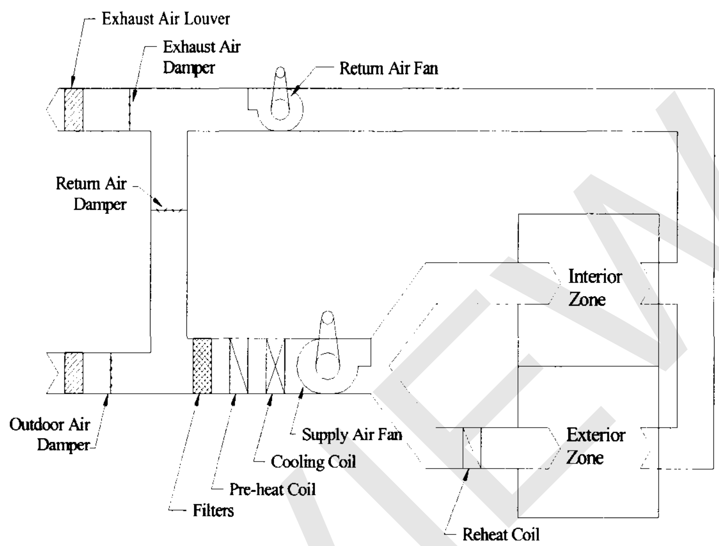

Figure2-1: Schematic of the SAHU

The economizer control arrangement can be adopted by the SAHU system. When the outside air temperature is sufficiently low, the outside air is used to provide cooling. Significant mechanical cooling can be saved by an economizer arrangement [1].

The SAHU system can be applied in commercial buildings due to its terminal reheat, which permits zone or space control for areas of unequal loading. It may also provide heating or cooling of perimeter areas with different exposures [2]. The control thermostat activates the reheat unit when the zone temperature falls below the zone temperature set point.

To conserve energy, the reset control should be provided to maintain the cold air at the highest possible temperature that satisfies the cooling requirement of the critical zone. However, supply air temperature resetting is limited by the interior zone cooling and humidity requirements. The exterior zone requires significant reheat.

2.2 The two dedicated air handling unit (TAHU)

The two dedicated AHU system (TAHU) is designed to separate the interior zone and exterior zone unit operations, as shown in Figure 2-2. The system consists of two identical SAHU units: one for the interior zone and the other for the exterior zone. The TAHU system is also an all-air system and inherits advantages of the SAHU system such as economizer control. Two separate units supply dedicated cold air to the interior zone and exterior zone respectively.