Dampers and Airflow Control

Laurence G. Felker and Travis L. Felker

American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

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Travis L. Felker

American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Atlanta



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In memory of Laurence Patrick Felker, 1919–1995

Paperboy

Chimney sweep

WWII halftrack gunner

Husband

HVAC controls sales manager

Father

Grandfather

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Introduction

GOAL OF THIS BOOK

Fans, duct systems, duct elements (such as filters and coils), dampers, and actuators all work together to control airflow. This text provides resources for building good judgment of the engineering principles needed to size, select, install, and adjust control dampers. Mechanical designers; mechanical and control contractors; and testing, adjusting, and balancing (TAB) contractors are the target audience of this book. Each specializes in a different part of the heating, ventilating, and air-conditioning (HVAC) system. Some material presented here is already familiar to each of these groups, and some material falls outside their normal areas of concern. For example, the information on loss coefficients and pressure loss is basic to the mechanical engineer; however, it is unfamiliar to most control contractors. Much of the subject material bridges gaps that exist between disciplines. The gaps observed in air systems are as follows:

- Lack of understanding of the final control element—the damper
- Lack of understanding of the detailed methods of the other trades on a project
- Lack of understanding of the complexity of airflows

There are many articles published regarding, for example, indoor air quality (IAQ) that say *what* actions to take. However, there are few suggestions for *how* they should be taken. This book addresses how to apply dampers within systems to achieve clearly defined goals.

The control of airflow in any commercial building is necessary for a variety of functions:

- Temperature control
- IAQ (ventilation)
- Envelope pressure control (mold and infiltration control)
- Elevator door operation
- Exterior door operation
- Exhaust
- Makeup air
- Pressure cascade from one zone to another
- Mitigation/control of chemical, biological, and radiological (CBR) release
- Smoke containment using shaft and wall dampers
- Smoke control using pressure differentials
    - Atria and large-space smoke extraction
    - Stairwell pressurization
    - Egress corridor smoke control
    - Zone smoke control

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Fans and dampers are the primary control devices for airflow management. Fans are adequately covered in many available technical publications, such as those published by the Air Movement and Control Association (AMCA 2002). However, this is the first book written about dampers. Many articles and manufacturer bulletins exist, and product information is available from manufacturers, but nothing is comprehensive.

The principles explained are applicable to all damper applications. Fire and smoke control texts offer good insight into airflow strategy and tactics and are sources of information not available elsewhere. For more information, see Chapter 16.

PROBLEMS

Studies of building tenant complaints by the International Facilities Management Association indicate that the number-one problem is temperature control (IFMA 2003). Other studies show that the number-one cause of IAQ complaints is the ventilation system (Seppänen et al. 2002; NIOSH 2007). While people do not complain on a daily basis about IAQ, they do complain about temperature. A system not controlling temperature well is almost inevitably not controlling ventilation adequately to protect tenants from health problems. Nor are the owner, architect, and mechanical consultant protected from lawsuits (Katz and Portner 1993).

ANSI/ASHRAE Standard 62.1-2007, Ventilation for Acceptable Indoor Air Quality (ASHRAE 2007a), focuses on ventilation. *ANSI/IESNA/ASHRAE Standard 90.1-2007, Energy Standard for Buildings Except Low-Rise Residential Buildings* (ASHRAE 2007b), provides guidance on energy use. Application of each standard depends on airflow. When applying ASHRAE Standard 62.1, particularly in sophisticated applications like dynamic reset (Stanke 2006), it is necessary to ensure the dampers can perform correctly.

Seventy percent of the total number of commercial buildings are owner occupied. The owner and occupants directly benefit from IAQ; however, building owners have limited finances, and it is normal to consider first cost as a primary concern, meet minimal code requirements, and ignore life-cycle costs. An engineer typically works with time, financial, code, and standard constraints, and the mechanical designer has to do more work at the same pay to meet a high level of standards. Efforts by the U.S. Green Building Council (USGBC 2007) are a step in the right direction toward bridging the gap between building costs and good IAQ. Knowledge of dampers also helps engineers and mechanical designers avoid problems and contributes to optimal design and cost efficiency.

Poor temperature control causes lost productivity and wasted energy. Inclusive formal surveys are not available on built-up systems; however, performance of most packaged equipment is suspect. For example, according to the California Energy Commission "Small System Design Guide" study,

> Economizers show a high rate of failure in the study. Of the units equipped with economizers, 64% were not operating correctly. Failure modes included dampers that were stuck or inoperable (38%), sensor or control failure (46%), or poor operation (16%). The average energy impact of inoperable economizers is about 37% of the annual cooling energy (Jacobs et al. 2003).

In the authors' experience, about 15% of buildings have airflow problems that lead to bad temperature control, IAQ deterioration, space pressurization irregularities, and wasted energy. Another 20% can limp along for years with moderate troubles and property owner indifference. Seasonal difficulties are common.

There are no airflow or pressure control contractors. The temperature control and TAB contractors are responsible for airflow and pressure control, but first they require a solid mechanical engineering design. The control contractor tends to think first of the sensor and logic portion of his system and last about the final control element. There is little information available on how and why to size dampers. Both valves and dampers are fluid-flow control devices, and proper sizing requires a mechanical engineering approach.

It is not atypical for engineers to design the mechanical system and then overlay the control system. The two must be designed together. The controls can fine-tune a good

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mechanical design; however, they must be included as a part of the design for maximum effectiveness. Controls cannot compensate for many mechanical design problems.

Since each building is unique, and the mechanical system must work the first time, design is critical. Of course, the space, money, and time constraints placed on the mechanical designer are sometimes severe and shortsighted on the part of the architect and owner if long-term quality is a goal.

IMPORTANCE OF DAMPERS AND ACTUATORS

Dampers are the final control devices for almost all airflow in HVAC systems. Actuators are the interface between the control system and the mechanical system and are critical to accurate control.

Typically, 80% or more of direct digital control (DDC) outputs in the HVAC portion of the system go to actuators. If they are not positioned accurately, then all other portions of the air system suffer. Too often, the torque necessary to move a damper is the only selection criterion; accuracy is not an important issue. A controller cannot compensate for incorrect damper or actuator sizing. The TAB contractor or commissioning authority can only sometimes set airflows to correct for problems.

Concentration on the final control elements in the design process can solve most of these problems. Equipment sizing is very rarely a problem. The airflow system delivering most of the conditioned air to the occupants causes the difficulties. Factory-built mixing boxes control flow with difficulty due to space constraints. The willingness of design engineers to design around some space constraints leads to systems that work only part time.

AIRFLOWS IN A BUILDING AND SYSTEM

As the size of a project grows, there is more complexity and more chance for small miscalculations to become a major problem. New design ideas present a greater chance of problems. Figure I-1 shows some of the following sources of airflows that affect space conditions:

- Wind effect on intakes and exits (overflow and underflow occur periodically)
- Damper leakage
- Duct leakage—both return and supply
- Infiltration
- Exfiltration
- Cross flows from air handlers or multiple-tenant equipment
- Doors—both between internal spaces and to the outside

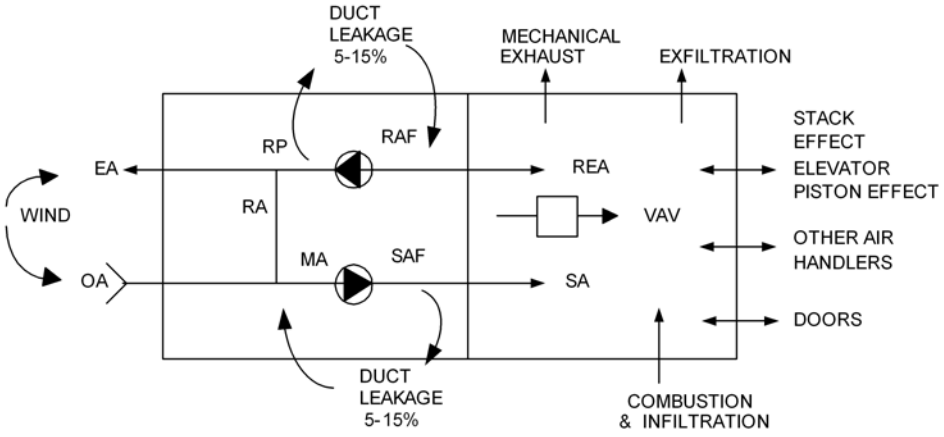


Figure I-1 Airflow paths in a typical system.

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- Elevator shafts
- Exhaust fans
- Plenum vs. ducted returns
- Relief-exhaust vs. return-air fans
- Ventilation air quality
- Heat-recovery equipment
- Flows in voids and hidden spaces
- Fans
- Stack effect and space or zone static
- Ventilation effectiveness (fresh air must be distributed well)
- Cross contamination of exhaust and intake (potentially a major problem)
- Variable-air-volume (VAV) box flow variation (typically, while the supply varies by location, the returns do not vary; this can result in irregular flow patterns)
- Leakage paths through ceilings and floors
- Leakage paths through pipes, chases, shafts, and any penetrations
- Unknown variables and factors

KEY TO TERMS

Our attention to airflow details is poor enough that we have not defined terms for all distinct duct flows. The tee where recirculation and exhaust air diverts to exhaust air and return air is the return-relief plenum. All the recirculation and relief air for an air-handling unit (AHU) flows through this point, yet it does not have a commonly accepted name. This indicates the weakness of hydraulic analysis we give to economizer duct systems. Relief air is used interchangeably with exhaust air; although, possibly, *exhaust* should be a term reserved for local exhaust or powered exhausts. Clarity in terminology is necessary for clear thinking.

The term *recirculation and exhaust air* could be used instead of return air. It diverts at the return plenum into relief air and recirculation air. In this book, each term is used to reflect actual practices.

AHU	Air-handling unit
DA	Discharge air—discharge from air handler going to supply diffusers or VAV boxes
EA	Exhaust air
IGV	Inlet guide vane
MA	Mixed air—part outdoor and part recirculated from the space
OA	Outdoor air
RA	Recirculation air or, alternately, return air
RAD	Return-air damper
RAF	Return-air fan
REA	Recirculation and exhaust air—part goes back to the AHU, and part is relieved.
REF	Relief-exhaust fan
RFA	Relief air
RP	Return-relief plenum—diverting tee in the return-air path
SA	Supply air to space
SAF	Supply-air fan
VAV	Variable air volume
VFD	Variable-frequency drive

TYPICAL PRESSURES IN AIR-HANDLING SYSTEMS

Figure I-2 shows the typical pressures in several types of AHUs. Damper sizing sometimes requires different methods, depending on the system. One must match system pressures with control methods and damper performance.

When there is only an SAF, the system has little flexibility. An exhaust damper is useless as an exhaust until the RAD closes, because the RP is negative due to the supply fan. The pressure loss in the ducts and space eats up most of the pressure on the discharge side of the SAF. Systems with this geometry have air coming in the exhaust until the RAD closes. Local

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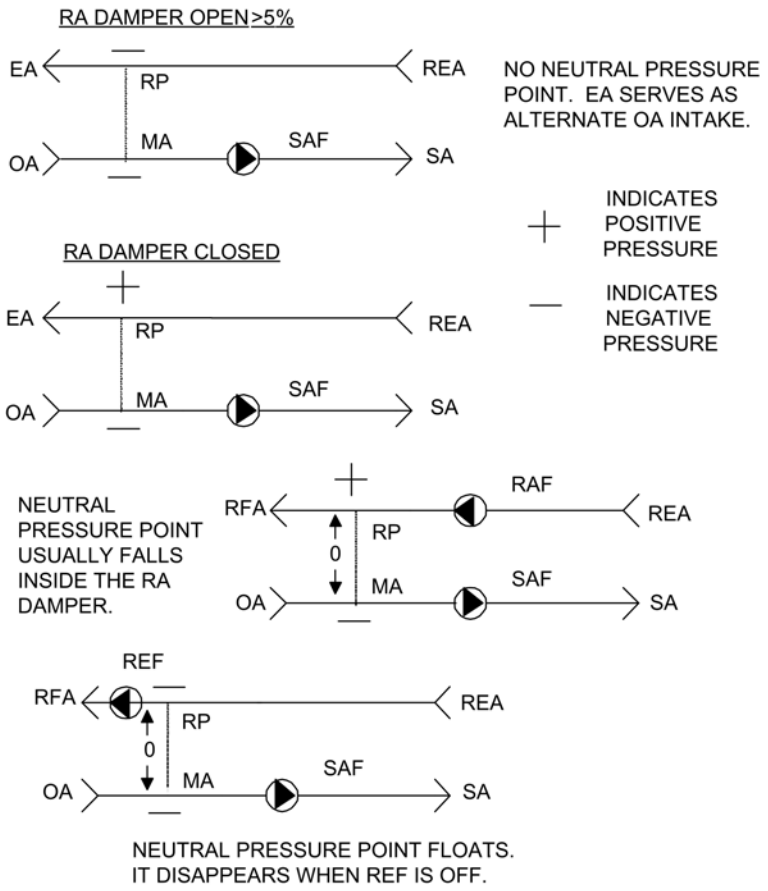


Figure I-2 Pressure points in a typical air-handling unit (AHU).

exhausts may help in economizer mode; however, the system overall is adapted for neither economizer operation nor space pressure control.

When there is both an SAF and an RAF, the RP is positive in all damper positions (unless the supply overpowers the RAF in error). The MA is negative; the value varies with the damper positions. When the OA damper is fully open, there is little pressure loss in that path. When the RAD is fully open (and the OA damper is closed), the RAF pushes air into the MA duct in some cases. The MA could go positive if the fans are unbalanced.

Typically, the MA is negative and the RP is positive. The balance or neutral pressure point where the static pressure is zero is often inside the RAD itself. The velocity pressure is always positive, since air is moving. The pressures at various points vary as the economizer dampers and VAV dampers proportion.

With an REF, there is no neutral pressure point when the REF is OFF. The SAF pulls the plenum negative. When the REF is ON, both the SAF and REF pull the duct negative until the RAD is closed. The balance point is within the RAD when it is closing; however, the neutral pressure point floats around in some cases. This is a difficult system to control.

The exact location of the neutral pressure point is not critical as long as the rest of the system is operating correctly.

Designing the fans' static pressures with respect to the duct and damper pressure losses at the various velocities is necessary. Given the unknowns, it is necessary to provide methods to balance the system. Balancing dampers and the use of VFDs help control airflow.

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A hydraulic analysis is always necessary to know what is going to happen inside an AHU. A built-up unit is easier to analyze since the components are known. A factory-built unit has the external static defined in the specifications; however, the dampers' response curves are unknowns.

A significant effort is being made by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and the federal government to reduce energy consumption. The concept of designing buildings that have a net zero energy use has gained traction. Development of ultra-efficient insulation, energy recovery, construction methods, equipment, and control tactics, along with solar and wind generation, could make concept a reality in some cases. The first steps toward net zero energy use buildings have been taken (ASHRAE 2008a).

New control and damper methods may reduce pressure loss and, thus, energy loss. In this book, an increase in damper pressure loss to balance part of a system is one basic tactic. This is best for control; it is not best for energy use, although the increase may be very slight.

Methods that are more sophisticated are applied after the basics are understood. One such method, untried and untested, is presented in Chapter 15, "Control Systems." DDC is required for sophisticated control. Most economizer and thermostat systems are simple analog and digital output devices. While they are much more flexible than old pneumatic controls, they are not as desirable as we can imagine. Once set, they are difficult to fine-tune. Canned programs and tactics are desirable so that the control contractor programmer does not have to reinvent the wheel with each system setup. Yet canned programs accept average methods and do not fine-tune for the idiosyncrasies that are normal in every system. It costs money to have the consultant and contractors review, fine-tune, continuously monitor, and recommission buildings. There is a trade-off between energy saved and cost of labor. Apply specialist knowledge to gauge the value of different actions.

OVERVIEW

This book concentrates on outdoor, recirculation, and relief damper operation in air-handling systems. This includes operation for economizers, OA intake for ventilation, and space pressurization. Apply the principles used for the economizer dampers to all similar applications. The principles apply also to VAV systems, refrigeration condensers, generators, relief dampers, and other simpler single-damper applications.

While the term *economizer* refers to the use of OA for free cooling, the ventilation minimum is maintained by the same controls, actuators, and dampers in most cases, and the two functions are usually inseparable. In this book, the word *economizer* refers to both functions unless specifically separated. Dampers operate in conjunction with other duct elements in order to obtain good airflow control. Control airflow by sizing and selecting dampers with respect to duct systems, by applying actuators and control loops properly, and by coordinating damper control in the entire system. It is necessary to develop engineering judgment based on various associated topics.

The *2009 ASHRAE Handbook—Fundamentals* (ASHRAE 2009) covers infiltration, ventilation, duct and fitting losses, stack effect, and other basics. The Sheet Metal and Air Conditioning Contractors National Association publishes material covering areas not covered completely elsewhere and some of the explanations are more basic (SMACNA 2002a, 2002b). Smoke-control texts provide strategy and tactics not covered elsewhere. The AMCA offers an excellent base of information that is well worth studying (AMCA 1986, 2002, 2003, 2006a).

There has been a scarcity of damper testing information in the past. Several ASHRAE-sponsored projects have addressed this in part. RP-1157, "Flow Resistance and Modulating Characteristics of Control Dampers" (Van Becelaere et al. 2004), tested the proportional characteristics of a variety of dampers in different geometrical arrangements and provided new and more accurate data, which are used extensively in this book.

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