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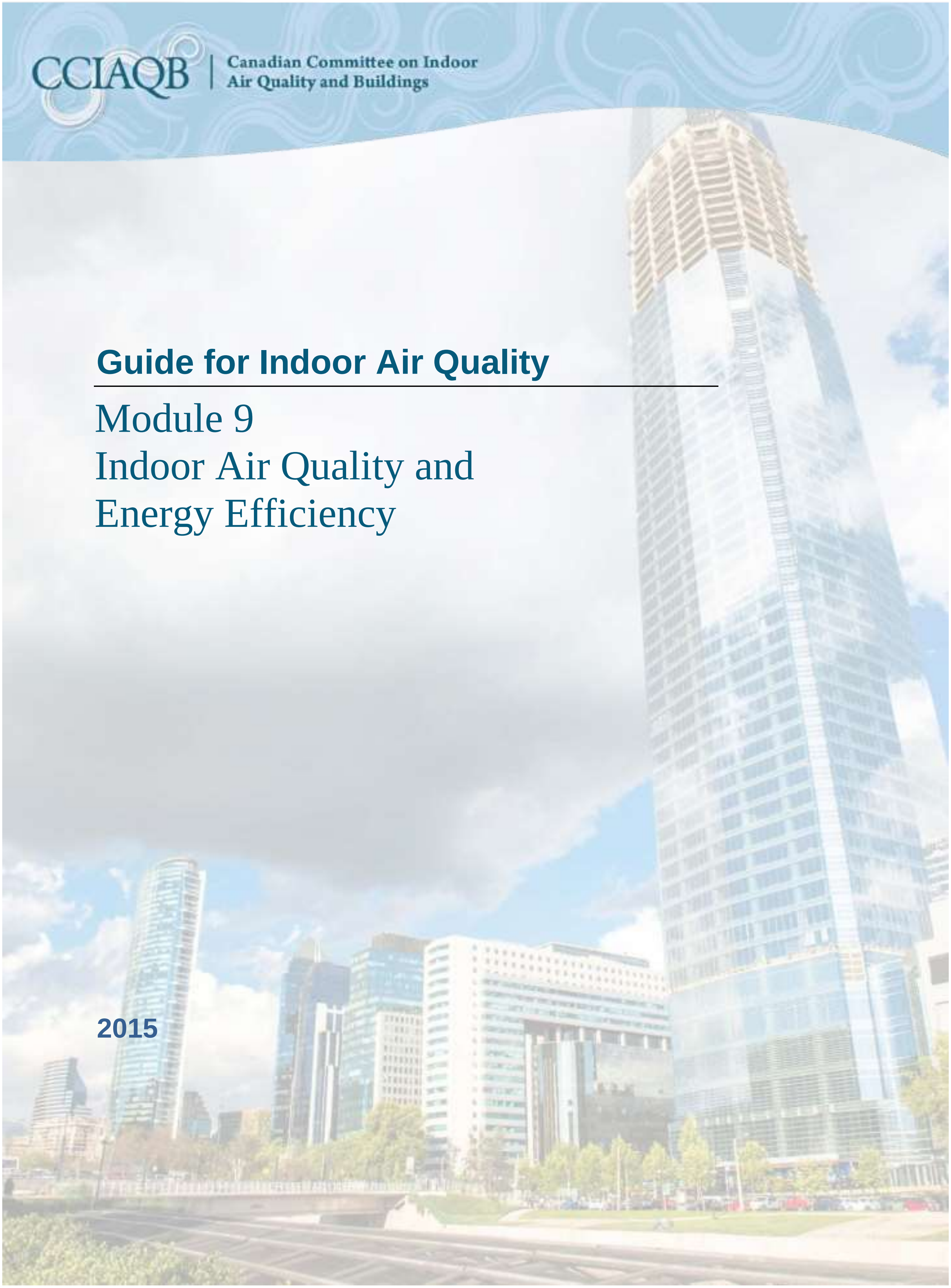

Guide for Indoor Air Quality

Module 9
Indoor Air Quality and Energy Efficiency

2015

Canadian Committee on Indoor Air Quality and Buildings (CCIAQB)

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Indoor air quality is a very complex issue and there is currently a significant gap between knowledge of the effects of indoor air quality on the health of occupants and the effectiveness of various air quality technologies and solutions. User discretion is advised.

Preamble

The objective of the CCIAQB is, ultimately, to improve indoor air quality for all Canadians in every type of building. The CCIAQB has decided that its initial focus should be on buildings where many Canadians spend time outside their home, working, learning, shopping, being entertained, etc. For the most part, these buildings have relatively complex heating, ventilating and air conditioning systems that are operated and managed by knowledgeable persons. The table below gives examples of buildings that are covered using the classification found in the National Building Code of Canada (NBC). Documents produced by the CCIAQB are primarily intended for the use of building operators and facility managers, but the information contained in the guides can be helpful to anyone seeking a general understanding of indoor air quality issues.

The Committee welcomes feedback on the documents as well as ideas for the development of new materials. Contact the CCIAQB Secretary at info@IAQforum.ca or register on the website at www.IAQforum.ca

NBC Classification	**Examples**
Group A, Division 1	Theatres, movie theatres and other facilities for the performing arts
Group A, Division 2	Art galleries, museums, libraries, educational facilities (schools, colleges and universities), gymnasia, air and rail terminals
Group A, Division 3	Arenas and swimming pools
Group C	Apartments, hotels, college residences
Group D	Offices, including medical and dental offices
Group E	Department stores, supermarkets, shops, retail space

Guide for Indoor Air Quality
Module 9 - Indoor Air Quality and Energy Efficiency

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1. Purpose of this Module

This module provides guidelines for achieving acceptable indoor air quality (IAQ) in existing buildings using energy-efficient methods and systems that reduce energy use. The information presented here targets building operators who manage facilities such as offices, retail operations, educational facilities and hotels, but is not limited to such buildings. However, this module does not cover industrial or institutional buildings such as hospitals and penitentiaries.
This document is part of a series of modules forming the CCIAQB *Guide to Indoor Air Quality* available at www.IAQforum.ca. For definitions and acronyms refer to *Module 1 – Introduction to Indoor Air Quality (IAQ).*

2. Background

"The complex relationship between indoor and outdoor environmental conditions, coupled with the impacts of climate change, requires a paradigm shift towards creating buildings that are comfortable and healthy for the occupants yet also energy efficient"[1].

It is widely recognized that maintaining acceptable IAQ is extremely important for human health, comfort, and productivity. Maintaining good IAQ does not have to come at the expense of energy efficiency. There are many examples of IAQ tools, techniques and strategies that are energy efficient and reduce building energy use. Such examples can be found in the previous modules of this series (e.g., *Module 6 – Scent-Free buildings*). Most energy conservation measures are compatible with good IAQ or can be made compatible by adopting certain precautions. Many energy efficiency measures that have the potential to degrade the quality of the indoor environment only require minor adjustments without sacrificing cost effectiveness (see *Module 3 – Custodial Activities, Maintenance, Repair and Renovation,* and *Module 6 – Scent-Free buildings* for further discussion).

[1] From ASHRAE conference document 2013

There is some argument that the focus on energy efficiency has overshadowed the concerns related to maintaining adequate IAQ. In striving to make buildings more energy efficient certain issues relating to IAQ may be overlooked. For example, a building may experience a worsening IAQ if the building envelope is made overly airtight in an attempt to reduce air infiltration, unless supplementary ventilation is provided. Therefore, any measures taken to improve energy efficiency must also consider the potential impact on the building IAQ. It is important, thus, to highlight the tools, techniques and strategies that address both energy efficiency and IAQ, and this guide will provide such examples. Some examples will present activities that building managers and operators regularly and conventionally do to maintain acceptable IAQ, and some examples will focus on new and innovative information that building operators and managers may not currently be aware of.

3. Introduction - Indoor Air Quality and Energy Efficiency in Buildings

3.1 What is an Indoor Air Delivery System?

All habitable buildings require some supply of outdoor air. The indoor air delivery system is the structure by which buildings receive that supply. Indoor air delivery systems can be passive, where openings in the building allow the outdoor air to enter and leave the building; or mechanical, where a mechanical ventilation system is used for either or both of these purposes. Depending on the climatic conditions, the outdoor air may need to be cooled or heated prior to being distributed within the building, in which case we refer to a Heating Ventilation and Air Conditioning (HVAC) system. Additionally, humidification, dehumidification, and/or filtration of the outdoor air may be required. All the different processes undertaken by an active air delivery system have associated energy costs.

3.2 How is the Indoor Air Delivery System Connected to a Building's Energy Efficiency?

The HVAC system influences the building overall energy efficiency because of its energy use. An inefficient or improperly functioning HVAC system will negatively impact both the building energy efficiency and the building IAQ by providing inadequate ventilation.

An energy efficient building manages indoor and outdoor air efficiently. This means having a well-maintained and efficient system by which the outdoor air enters and leaves the building through either mechanical or natural air delivery systems. Beyond IAQ, building energy efficiency measures may also affect the levels of noise, light and thermal comfort within the building.

The focus on energy efficiency in buildings has both positive and negative consequences on IAQ. On one hand, almost all standards and codes developed for energy efficiency have sections that focus on the connection between IAQ and energy efficiency, and/or discuss how the two overlap in practical ways. On the other hand, the popular adoption and promotion of energy efficiency in buildings focuses on energy savings and costs reductions associated with ventilation and air conditioning, mostly by reducing air-infiltration through improved airtight envelopes. This can be detrimental to IAQ, as it will reduce the supply of fresh outdoor air and the exhaust of indoor air.

3.3 Energy Efficient Building and IAQ Codes, Standards, Documents, Organizations, and Rating Systems

Recent consultations on energy efficiency in buildings have highlighted how the neglect of IAQ issues has become problematic for human health, comfort and productivity, as well as for the development of sustainable building energy strategies. It is now recognized that building energy efficiency strategies must take IAQ into consideration. There are a variety of standards worldwide that assess a building's energy efficiency and rate buildings accordingly. There are also a variety of standards and codes that have led the way in determining what is acceptable IAQ and how indoor air delivery systems are designed, built, installed, maintained and operated. Examples of standards, programs or codes that provide regulatory guidance on the intersection between energy efficiency and IAQ include the following:

Table 3.1 – Standards and Codes

Standards/Codes	Location
National Energy code of Canada for buildings 2011	https://www.nrc-cnrc.gc.ca/eng/publications/codes_centre/2011_national_energy_code_buildin gs.html
NRCan Energy efficiency documents for buildings	http://www.nrcan.gc.ca/energy/efficiency
National Building Code of Canada 2010	http://www.nationalcodes.nrc.gc.ca/en g/nbc/
Provincial codes (i.e. Alberta 2006; Ontario, 2012; BC 2012)	Found on the provincial government website of each province
ANSI/ASHRAE Standard 62.1-2013 - Ventilation for Acceptable Indoor Air Quality ANSI/ASHRAE Standard 62.2-2013 - Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings	https://www.ashrae.org/resources-publications/bookstore/standards-62-1-62-2
ASHRAE Standard 55–2013 Thermal Environmental Conditions for Human Occupancy	https://www.ashrae.org/resources-publications/bookstore/standard-55
ASHRAE Standard 100 -2006 Energy Conservation in Existing Buildings (review draft)	https://osr.ashrae.org/Public%20Review%20Draft%20Standards%20Lib/Std-100-2006R-APR1-Draft_2011-0411_v4.pdf

ASHRAE Standard 90.1 2013 Energy Standard for Low Rise Buildings except Low-Rise Residential Buildings	https://ashrae.iwrapper.com/ViewOnline/Standard_90.1-2013_I-P
ASHRAE Standard 90.2 2007 Energy Standard for Low Rise Buildings	https://ashrae.iwrapper.com/ViewOnline/Standard_90.2-2007
Programs/Certification	
LEED (Leadership in Energy and Environmental Design)	http://www.cagbc.org/Content/NavigationMenu/Programs/LEED/GoingGreenwithLEED/default.htm
BOMA BEST (Building Environmental Standards)	http://www.bomabest.com/
BREEAM (Building Research Establishment Environmental Assessment Method)	http://www.breeam.org/
PassivHaus	http://www.passivehouse.ca/
Documents/Guides	
Canadian Committee on Indoor Air Quality and Buildings (CCIAQB) 2013	http://iaqforum.ca/
Commercial Buildings Incentive Program (CBIP)	https://www.nrcan.gc.ca/audit/reports/ 2007/1086
The Environmentally Responsible Construction and Renovation Handbook 2000	http://www.tpsgc-pwgsc.gc.ca/biensproperty/gd-env-cnstrctn/indexeng.html
EnerGuide 2013	http://oee.nrcan.gc.ca/energuide/index.cfm
ASHRAE's Indoor Air Quality Guide: Best Practices for Design, Construction and Commissioning 2009	http://cms.ashrae.biz/iaqguide/pdf/IAQGuide.pdf?bcsi_scan_C17DAEAF2505A29E=0&bcsi_scan_filename=IAQG uide.pdf
EPA Indoor Air Quality (IAQ) documents and modules	http://www.epa.gov/iaq/
IAQ in Large and Commercial Buildings- IAQ Building Education and Assessment Model (I-BEAM)	http://www.epa.gov/iaq/largebldgs/ibeam/index.html
Building Air Quality (BAQ)- A Guide for Building Owners and Facility Managers	http://www.epa.gov/iaq/largebldgs/baq _page.htm

3.4. Factors to Consider in Developing Energy Efficient IAQ Strategies

for Buildings – The Building Lifecycle and Energy Efficient IAQ

Before developing a comprehensive strategy for incorporating energy efficient IAQ measures in an existing building some of the following aspects should be considered:

- **Balancing energy efficiency targets with IAQ targets**. Prior to any building intervention it is very important that building managers and owners are aware of existing standards or targets for building IAQ and energy efficiency. Most certification programs, standards and building codes for energy efficiency also include sections on IAQ. Many certification programs also have benchmarking criteria for energy efficiency and IAQ. These need to be included in the initial baseline IAQ profile of the building and the subsequent IAQ audits.
- **Cost efficiency versus energy efficiency and IAQ**. Typically, enhancing both the energy efficiency and the IAQ efficiency will result in long-term monetary savings for building owners and operators. The initial investment to modify, enhance or retrofit an existing building may be substantial, but expenditures may be recovered over a relatively short period of time through reduced maintenance and operating costs.
- **Occupant comfort, IAQ and energy efficiency**. Poor IAQ has a negative impact on occupants health, comfort and productivity and represents an indirect cost. This is a direct concern to building operators and tenants. Therefore, any assessment of the cost savings associated with the implementation of new energy efficiency measures must take into consideration the potential negative cost resulting from a degraded IAQ.

4. Strategies for Enhancing Energy Efficient IAQ- Introduction

Generally, enhancing a building's energy efficiency, performance and IAQ, centers upon the following five strategies:

1. Reduce the energy load of the building systems.
2. Make use of the available environmental thermal resources.
3. Improve the energy efficiency of the HVAC system by using energy efficient components.
4. Optimize the control and operation of the building systems.
5. Offset the HVAC system energy input with renewable energy sources (if possible).

Ideally, these strategies should be considered during the building design phase. However, building owners and operators may not be in the position to redesign an existing building. This section will expand upon a variety of aspects that building operators and managers need to know in order to make informed decisions when trying to optimize energy efficiency and IAQ in existing buildings. Five interconnected issues will be discussed:

1. Understand the different types of Infiltration, Ventilation Systems and Supply Strategies for buildings.

2. Optimize and maintain building IAQ and energy performance using HVAC equipment and systems.
3. Optimize and maintain building IAQ and energy performance using the building's exterior and interior environment.
4. Maintain and optimize the building performance.
5. Implement an ongoing monitoring and evaluation of the HVAC system and the building.

4.1 Types of Ventilation Systems and Supply Strategies

Building ventilation can be achieved through either natural ventilation, mechanical ventilation, or hybrid ventilation that combines both. Each of these systems utilize energy in different ways and have different advantages and disadvantages for building IAQ and energy efficiency. It is important to understand the types of ventilation systems and identify potential strategies that building managers and owners could use to enhance IAQ and energy efficiency.

4.1.1 Natural Ventilation Systems

Natural ventilation systems (NVS) rely on pressure differences to move fresh air through a building. It is useful to think of a natural ventilation system as a circuit, with equal consideration given to supply and exhaust/return air. Three common examples of natural ventilation systems that may be relevant for existing buildings are: wind driven crossventilation, stack driven ventilation and night-time ventilation.

Wind driven cross-ventilation uses pressures generated on the building by the wind to drive air through building openings from the windward side to the leeward (other) side. This infiltration system works best in climates with lots of wind and in buildings that are tall and narrow and have many small openings that can be opened or closed.

Stack driven ventilation uses the buoyancy effect to move the air throughout a building, the warmer and less dense air being pushed up by the cooler and less dense air below. Warmer indoor air escapes through openings located high in the building, while cooler outdoor air enters the building through its lower openings. This type of infiltration is advantageous for buildings with large footprints, which are not situated in windy locations. However, this type of systems may be problematic in terms of building noise and fire regulation codes, and can result in diminished air flow and increased heat gains in the upper zones of the building.

Night-time ventilation systems use cold night air to cool down a building and offset or reduce the heat gains absorbed by the building during daytime. Night-time ventilation can be driven by natural forces (i.e., stack or wind), but may also use auxiliary fan power, either to provide sufficient airflow at times when the natural forces are weak, or to allow for smaller ducts (causing greater resistance) to be used. These systems are best in buildings that are unoccupied at night.

In terms of energy efficiency and IAQ, natural ventilation systems have both benefits and drawbacks. Their main advantage is their passive nature, which often leads to lower operating costs compared to mechanical ventilation systems. Many building occupants respond positively to natural ventilation systems, perceived as systems that allow for more “fresh” outdoor air to enter the building, enhancing its IAQ. It is argued that access to a building’s openings that allow for individual control of the airflow and temperature improves a building’s IAQ. Additionally, natural infiltration may also reduce the amount and size of the building ductwork, reducing the amount of re-circulated air. However, natural ventilation systems may still require systems to filter the supply of outdoor air, which may not be as ‘fresh’ as the occupants perceive it to be, as well as systems to heat or reduce its humidity. It is useful for building managers, operators and owners to determine if natural ventilation is the right strategy for each building case, based on design (height, layout, etc.), site orientation, climate and occupant use.

4.1.2 Mechanical Ventilation Systems

Mechanical ventilation systems use a network of fans and ducts to circulate supply and return air within a building, as well as, remove moisture, odors and other contaminants. This network of mechanical components is generally described as an HVAC system. Increasingly, in response to the need for energy efficient building applications, mechanical ventilation systems have become more efficient in terms of both energy use, as well as addressing the occupants thermal and comfort needs.

Three basic types of HVAC systems are commonly used in Canada: Constant Air Volume Systems; Variable Air Volume Systems and Demand Controlled Ventilation. Each of these systems encompass many variations and configurations.

Constant air volume systems (CAV) use a central thermostat to automatically regulate the air temperature within a building, controlling the space temperature by altering the temperature of the supply air, while maintaining a constant airflow. Most CAV systems are small and serve a few zones but they can also be used in larger buildings with multiple zones (dual and multizone CAV systems). Most often CAV systems use an on/off control rather than modulation of the supply air temperature to vary the heating or cooling capacity. This type of systems do not generally provide flexible temperature control of the areas being served, which may affect their ability to modify the IAQ in a given area. In addition, CAV systems are generally not as energy efficient as other mechanical ventilation systems because their heating and cooling coils operate at the same time.

Variable air volume systems (VAV) control the temperature of a space by varying the airflow of the supply air, while keeping the supply air temperature constant. VAV systems use a variable speed fan controlled by either a variable frequency inverter, the position of the fan inlet dampers or other airflow control devices. VAV systems can serve multiple zones within a building and can provide more individual control over given zones, being typically more energy efficient than CAV systems. They are also more flexible and better at dehumidification and can address the varied IAQ needs of different areas of the building. However, concerns were raised regarding their ability to adequately dilute the indoor air contaminants at part load conditions.

Demand controlled ventilation (DCV) systems are a more precise type of VAV systems wherein the amount of supply air is adjusted based on the ventilation needs. The objective of a DCV is to keep ventilation rates at or above the design specifications and the code requirements, saving energy by avoiding excessive ventilation. DCV systems are often implemented in spaces with high and variable occupancy, such as auditoriums. Some DCV systems automatically modulate the ventilation rates based on measured indoor concentrations of carbon dioxide (CO_2) emitted by the building occupants, and/or by nitrogen oxide (Nox) and time-of-day (TOD) sensors, which allow for greater occupant IAQ control. DCV systems generally use less energy for fan operation, and heating and cooling of the supply air. DCV systems controlled based on space temperature also eliminate the need for supplementary heating when the cooling capacity of the supply air exceeds the cooling capacity needed. However, improper selection and design of the airflow control and supply air devices is a common cause of excessive noise and drafts associated with DCV systems. In addition, direct occupant control of the thermostats can result in over or under cooling of the building.

4.1.3 Hybrid Ventilation Systems

Hybrid ventilation systems combine both natural and mechanical systems. In this case building owners, designers and operators weigh the pros and cons of each system and develop a combined system of components for the building. Mechanical cooling and ventilation systems may be used to supplement the natural ventilation and vice versa. Hybrid ventilation systems are practical because in the Canadian climate buildings cannot rely exclusively on natural ventilation all year round. Increasing awareness about natural ventilation methods have made this type of systems more desirable to building occupants, managers and owners.

4.2 Maintenance and Optimization of HVAC Equipment and Systems for Energy Efficient IAQ

4.2.1 Optimizing HVAC Systems for Energy Efficient IAQ

Optimizing an HVAC system for indoor air quality and energy efficiency is directly connected to maintaining the building equipment, and ensuring that the HVAC system is regularly inspected and cleaned in accordance with the standards, programs and codes listed in Table 3.2. According to these standards/codes/programs it is important to:

- Ensure that HVAC systems perform as they were designed;
- Ensure that HVAC systems do not circulate and distribute dust, dirt and other contaminants into the building airflow system;
- Inform building operators and managers if the HVAC system requires different components, settings, etc.;

- Inform building operators and managers if the HVAC system requires more than just maintenance and can only be optimized through replacement.

In addition to maintaining the components of an HVAC system, it is also important to ensure that the system components are optimized to deliver high quality indoor air in an energy efficient manner. DCV systems, most VAV systems and some CAV systems can be made more efficient in terms of both energy use and enhanced IAQ through the following general strategies (Table 4.1)[2]:

Table 4.1 - Optimizing HVAC Systems	
HVAC issue or component Description/Discussion	**Recommendations**
Reduce the HVAC system outdoor airflow rates and minimize exhaust and makeup (ventilation) rates when possible. While reducing outdoor flow rates is considered best practice by most standards and codes for the purpose of maximizing energy efficiency, reducing airflow rates must be done with caution in compliance with the most stringent local, provincial or federal requirements. It is easy to change the operational settings to meet a minimum setting, however the building manager or operator must ensure that the building IAQ	In single- and dual-duct VAV terminals, reduce the minimum airflow to the lowest practical setting to meet the ventilation requirements. Reduce the use of outdoor air during the morning warm-up when the building is unoccupied, while still ensuring that the building air is adequate prior to occupancy. Convert mixing air supply systems into displacement ventilation systems to create a temperature stratification in spaces with high ceilings and predominant cooling needs. Control the supply fan VSD (variable-speed

[2] Mari-Liis Maripuu (Ph.D.) (2011) Demand controlled ventilation (DCV) for better IAQ and Energy Efficiency, HVAC journal online http://www.rehva.eu/publications-andresources/hvac-journal/2011/022011/demand-controlled-ventilation-dcv-for-better-iaq-andenergy-efficiency

meets the relevant standards and codes as well. This involves careful evaluation, testing, balancing and adjustments to ensure that sufficient outdoor supply air requirements are met in all areas of the building.	drive) based on the static pressure needs of the system. Reset the static pressure set point dynamically to the lowest practical setting that meets the zone set point. Reset the set point of the VAV/DCV system supply air temperature when the system is at minimum speed to provide adequate ventilation. For CAV systems, if conversion to a VAV/DCV system is impractical, reset the supply air temperature in response to the load. Dynamically control the heating duct temperature as low as possible and the cooling duct temperature as high as possible, while meeting the load.
Insulation of HVAC components	Insulate the HVAC ducts and pipes, particularly if they are outside of the conditioned space. Insulate the fan-coil units and avoid installation in unconditioned spaces. It is important to note that insulation must be properly installed to ensure that off-gassing of insulation materials (e.g., spray insulation) does not occur or enter into the HVAC airflow system. Particular emphasis should be placed on selecting an insulating material with minimal VOC offgassing.
Economizers HVAC systems are made more energy efficient and cost effective through the use of economizers. Air-side economizers modulate the use of cooler outside air to provide free cooling to the space, using dampers, actuators, sensors and controllers to regulate how much outside air is introduced into the building, how much return air is recirculated back into the building, and how much return air is exhausted from the building. Water-side economizers use cooling towers that provide chilled water without the energy penalty of using compressors.	Economizers are ideal in cold climates and have the potential to improve the indoor air quality as they use the cooler and dryer outside air as a means of cooling the indoor space. Economizers work best with a four-season reset strategy, as in the summer and spring they usually do not operate as frequently due to higher temperature and humidity of the outdoor air.

Centralized versus occupant regulated ventilation DCV and VAV systems allow for adjustment of airflow and temperature in different zones or rooms of the building. This offers the occupants the option to set the controls themselves according to their individual needs. However, the occupants may not always set the controls in ways that are optimal for energy efficiency or IAQ.	There is a need for occupant education and training about IAQ and ventilation systems. Considerations whether DCV/VAV controls and airflow openings should be controlled by the occupants or, centralized, by the building manager are important. Consider time scheduled ventilation and airflow methods that permit changes made by the occupants and allow for a more precise control based on occupancy, weather, time-of-day.
Optimizing HVAC cooling systems - Cooling towers and Chillers Water chillers and cooling towers are used in airconditioning applications to cool and dehumidify the air. Chilled water is distributed to heat exchangers in air handling units or to other devices that cool the air, and re-circulated back to the chiller or cooling tower to be cooled again. The actual amount of cooling that an air conditioning system receives from a chiller or colling tower depends on the air relative humidity and barometric pressure. It is important that a proper quantity of circulating water is available in the system at all times. Due to evaporation, water needs to be added regularly to the chiller or cooling tower basin. If the water level is too low, the pumps suck in air, if the water level is too high overflowing may occur, creating roof damage and possible leaks.	Limit the impact and growth of contaminants through water-treatment programs (use biocides in the circulating water or expose the water to ultraviolet light through chambers installed in the tower). Use biocides that are less likely to affect IAQ. Use a blow-down system that "bleeds off" a portion of the circulating water and replaces it with fresh water. Regulate the cooling tower/chiller water level by adding water to the basin, and use a float valve or an electronic level control that maintains water levels between a minimum and a maximum position. Use a meter on the cooling tower water line and read it daily or weekly to identify problems. Increase the supply air temperature to reduce chiller energy use.

Heat and Energy Recovery Ventilation Systems Employ heat recovery from the exhaust air for pre-heating or pre-cooling of the incoming outdoor air. Heat recovery ventilation (HRV) and energy recovery ventilation (ERV) systems provide excellent opportunities for saving energy, controlling humidity, and providing sufficient outside air to promote IAQ in buildings with high occupancy. Heat recovery systems transfer heat from the exhausted air to the incoming outdoor air. Energy recovery ventilation systems transfer both heat and moisture between the exhaust air and the incoming outdoor air via an air-to-air heat exchanger. This maintains the indoor humidity at appropriate levels, preventing the indoor air from becoming too dry in the winter and too moist in the summer.	ERV systems increase the potential for the downsizing of other HVAC equipment. Use ERV flat-plate heat exchanger systems and ERV rotating-wheel systems (enthalpy-wheel systems). Use exhaust capture systems in parking and semi-enclosed areas, which trap fumes and contaminant by-products from vehicle engines and prevent contamination of the building air. Use heat-exchangers with small diameter tubes, which allow for compact designs that provide a more efficient heat transfer and reduce fanpower requirements.
Filters with appropriate MERV ratings- HRV and ERV filters The minimum efficiency reporting value, or the *MERV rating*, is a measurement scale designed by ASHRAE (the American Society of Heating, Refrigerating and Air-Conditioning Engineers) to rate the effectiveness of air filters. It provides a precise and accurate air-cleaner rating for improved health, reduced cost and energy efficiency of HVAC systems.	Check for grading systems of filters to help determine which filters are most appropriate and efficient for the building HVAC system. It should be noted that the use of higher efficiency filters (higher MERV ratings) generally leads to a larger pressure drop across the filter due to the increased resistance of the airflow through the filter. As a consequence, more energy will be required to supply a given flow rate.

Optimize the efficiency of the heating and cooling distribution system - Part-load efficiency methods. Part-load performance of equipment is a critical consideration for HVAC sizing. Most heating and cooling equipment operate at their rated efficiency only when fully loaded (or working near or at their maximum output). However, HVAC systems are sized to meet design heating and cooling conditions that occur only a small percentage of the time. HVAC systems are intentionally oversized to handle peak loads and provide a factor of safety. Nevertheless, systems almost never operate at full load and, in fact, most systems operate at only 50% or less of their capacity.	Use systems and components that operate efficiently at part-load conditions, such as: Variable volume high efficiency fan systems and variable speed drive controls for fan motors; Variable capacity boiler plants (e.g., condensing boilers); Variable capacity cooling plants (e.g., modular chiller plants, multiple compressor equipment, and variable speed chillers); Variable capacity cooling towers (e.g., multiple cell towers with variable speed or two speed fans); Variable capacity pump systems (e.g., primary/secondary pump loops, variable speed pump motors); Use temperature reset controls for hot water, chilled water, and supply air. Ensure that HVAC components are well insulated and air ducts are sealed. Reduce demand charges through night-time precooling and sequential startup of equipment to eliminate demand spikes.
Variable Refrigerant Volume (VRF) A VRF system is an air conditioning system consisting of one outdoor condensing unit and multiple indoor evaporator units. The amount of refrigerant flowing to the multiple indoor units can be controlled, enabling differing capacities and configurations to be connected to a single condensing unit. The system offers individualized programmable control and simultaneous heating and cooling in different areas of the building. VRF systems use less copper tubing, minimizing the refrigerant path and maximizing the refrigeration efficiency. VRF systems can be used for cooling, heat pumping or heat recovery. They are modular and	Use VRF systems instead of split or multi-split air conditioning systems because, unlike multi split systems that turn on/off in response to one master controller, VRF systems continually adjust the flow of refrigerant to each indoor evaporator. These systems provide better air flow and less hot/cold spots, and have fewer maintenance issues. Use a VRF heat recovery system, which can provide additional energy savings. Use friendly, non-ozone depleting, refrigerants.
easy to install, and do not need ductwork, which reduces airflow loss. However, these systems require a separate ventilation system to be integrated into the building.	

Optimize Sensors and System Controls Sensors and controls optimize the performance of HVAC systems (e.g., reset set points according to the outside temperature, optimize start/stop times based on the building occupancy, etc.) and are used by DCV/ VAV systems to maintain optimum IAQ and reduce energy use. Sensors are also used to identify problems and issues, monitor the system performance, and establish baseline and benchmarking data for the building over time. Sensors installed in rooms/zones allow occupant-controlled set points and overrides. Examples of sensors include: temperature and humidity sensors that monitor the thermal comfort; carbon dioxide (CO2) and carbon monoxide (CO) sensors that monitor pollutants.	Include sensors that monitor potentially harmful volatile organic compounds (VOCs) emitted by cleaning supplies, paints, glues, furnishings, building materials. Such sensors can be added to other HVAC system sensors and control panel systems. Ensure that sensors and controllers have alarms and can notify or alert the building managers, operators and maintenance staff to issues before they start causing discomfort to the building occupants. Sensors with data ports allow quick network access and control to the building service personnel using a laptop computer and a network interface. Adopt smart controls that merge building automation systems with information technology (IT) infrastructures. Use night set-back, or turn off the HVAC equipment when the building is unoccupied. Install occupancy sensors with VAV systems to set-back temperatures and shut-off boxes.

4.2.2 Preventive and Regular Maintenance of HVAC Systems

Preventive and regular maintenance of HVAC systems improve IAQ and reduce energy use by removing contaminant sources[3]. Some examples of HVAC systems good practice maintenace are described in Table 4.2 (for additional examples refer to *Module 3 – Custodial Activities, Maintenance, Repair and Renovation*, Section 6):

Table 4.2 - HVAC Performance Improvement	
HVAC components/Issues	**Things to check or do**
General airflow	Measure the airflow and check against both standards/codes, as

[3] A preventative maintenance program should involve the evaluation of the condition of equipment by performing periodic or continuous equipment monitoring (predictive maintenance); the periodic inspection and servicing of a building and its equipment for the purpose of preventing failures (specific preventative maintenance); a strategy to stabilize the reliability of equipment using specialized maintenance services (proactive maintenance); and a maintenance plan used to create a cost-effective maintenance strategy to address dominant causes of equipment failure (reliability centered maintenance). See "Chapter 10 Preventative Maintenance", *Indoor Air Quality A guide for Stationary Engineers*, pp.174-197 for more information.

problems	well as any previous benchmarking or baseline data of HVAC system operation .
Evaporator and condenser coils and drain pans	Check for mold, fungus, dirt and dust on the outdoor air supply side. Clean and ensure that standing water has been drained.
Cooling towers	Cooling towers operate in environments that expose them to a range of contaminants. Dust, dirt, sand and silt can be introduced into the cooling tower from the atmosphere and in the tower water supply. These solids collect in the tower basin, erode circulationpump impellers, clog spray nozzles, and form scale on heattransfer surfaces. Organic matter, such as leaves, grass, pollen, and biological contaminants such as algae and bacteria can also be introduced into the cooling tower and its water supply and can collect in basins, nozzles, and heat-transfer surfaces. Particular care should be taken to avoid viable biological contaminants, such as bacteria, from propagating into the water. A water meter should be used in the tower basin to monitor water levels daily or weekly to ensure proper operation.
Mechanical HVAC components- fans, bearings, belts and motors	Ensure proper calibration, alignment, and tension of belts. Remove dust and debris, and ensure that fan motors move in the correct direction. Clear labels on the fan housing, pulleys, motor, and wires can prevent problems. If possible, replace standard fan belts with fan belts designed for minimum energy losses (such as cog belts).
Mechanical HVAC components- thermostats, controls	Ensure proper calibration of sensors and controls. Failed sensors are often the result of snap discs that cannot be calibrated or adjusted, as well as, broken wires. Problems often involve improper thermostat settings, fans running continuously during unoccupied periods, improperly installed resistors, and lack of night-time setup or set-back. Cycle fans during the occupied periods and check thermostats regularly to ensure optimal performance.
Air vents	Inspect air vents for mold and other pollutants.
Filters	Inspect filters routinely (every 6 months or less) and replace as needed.
Inspect area around air intake	Water can pool around air-handlers, and mold and bacteria growth can take place. The presence of mold near the air intake could lead to it being drawn into the building. Check for standing water around the air-handler.

Fix Leaks in Cabinet and Supply Duct (annually)	Annual check-ups should include a search for air leaks, replacement of screws or latches, and gasket patching or replacement. Cabinet and duct reliability is particularly important on the supply-air side where high pressure can force the air out through small cracks.
Clean and Adjust Dampers (annually)	All movable surfaces should be cleaned and lubricated. Check set points and test dampers by running them through their full range.
Clean Air Ducts	Remove dirt from the air ducts. Dirty air ducts are also indicative of problems with air filters and other HVAC components.
Check AC units	Ensure that the space around outdoor AC units are free of debris.
Economizers	If economizers are not working check that actuators and dampers are not broken or frozen.
Refrigerant	Check and adjust the refrigerant level. Change the refrigerant if needed.
Window air conditioners	Replace inefficient window air conditioners with high efficiency modular units or central AC systems (with high SEER rating).

Preventative maintenance does not include only regular inspections of the equipment, it also includes obtaining feedback from the building occupants, and monitoring complaints related to irregular smells and emergent occupant health issues. A regular method or procedure by which the occupants can register complaints or report issues with respect to their comfort (i.e. too cold/too hot) or health is instrumental in identifying issues of relevance to building IAQ and energy efficiency.

4.2.3 Upgrading of HVAC Equipment to Reduce Internal Loads

In addition to maintenance, in certain instances it may be necessary to change the existing HVAC components if they do not comply with applicable codes and standards for energy efficient IAQ. This is not as cost effective in the short term as a maintenance program, but ultimately will enhance the building quality and livability and may have cost savings advantages in the long term. There have been considerable advances in the development of HVAC equipment, which is increasingly more energy efficient and better at providing a high standard of indoor air quality through increased filtration and ventilation mechanisms and products.

4.3 Maintenance and Optimization of Building Energy and IAQ Performance – The Physical Building and its Surroundings

Building IAQ performance and energy efficiency also depends on the maintenance of the building itself. Optimizing the building interior and exterior to maximize its energy efficiency and comfort while still maintaining a high indoor air quality is recommended. This should be done alongside a comprehensive maintenance program for the building to remove potential sources of IAQ contaminants (such as high VOC emitting construction products), and ensuring that adequate custodial practices are in place. (For more discussion on this topic refer to *Module 3 – Custodial Activities, Maintenance, Repair and Renovation*). In order to optimize IAQ performance and energy efficiency of existing buildings the following aspects should be considered:

- Consider strategic placement of constructed barriers (i.e., fences, panels) and natural landscaping (i.e., trees, plants) to direct airflow, mitigate noises, smells and vehicular exhaust, create shade and reduce air-conditioning loads.
- Evaluate where cars are allowed to park relative to the building openings and the air supply intakes of the mechanical ventilation system. If vehicular exhaust is identified as an issue the implementation of a no-idling policy can be considered.
- Insulate and install vapor barriers in walls, ceilings and roofs for heat loss and moisture reduction through large surfaces, and eliminate the thermal bridges where the floor and the interior walls are anchored to the exterior walls. However, caution should be taken to ensure that insulation and vapor barriers are properly installed, as some types of insulations have been shown to contribute to poor IAQ when installed incorrectly.
- Utilize fans to circulate the air within the building, which may be advantageous for both natural and mechanical ventilation systems.
- Retrofit existing openings to make them more energy and sound efficient, or make them more accessible to the occupants for an enhanced control of the airflow.
- Replace single-pane and leaky windows with thermal/operable windows to minimize cooling and heating loss, and ensure that operable windows are properly maintained and can easily be opened and closed.
- Use operable windows for natural ventilation during mild weather conditions or when the outdoor conditions are optimal. Confirm that the facility has been designed for natural ventilation and that control strategies are available to operate the facility in the natural ventilation mode.
- Use airlocks to prevent unwanted infiltration of outdoor air pollutants. Thermally insulated doors and draft sealing can prevent heat losses and reduce the entry of airborne contaminants from parking garages or high-traffic passageways.
- Use lighting strategies that reduce the building reliance on mechanical systems and reduce the amount of contaminants moved through HVAC systems. Motion sensors and schedules, photoelectric dimmers that measure the amount of light in a zone and control the indoor light accordingly, or other strategies for switching the lights on only when needed, could be used to reduce the heat gains associated with indoor lighting and reduce the HVAC system load.
- Use daylighting strategies such as controlling daylight through louvers, glazing materials, types of window openings and window coverings.
- Use techniques that help reflect and absorb light/heat within the building (i.e., use of color and reflective paints), while ensuring that all product have low VOC emissions.
- Use environment-friendly materials that are both low emitting and energy efficient to reduce the amount of pollutants or contaminants introduced into the building during building retrofits and renovations.

- Adjust housekeeping schedules to minimize HVAC use.

4.4 Maximizing Energy Efficient IAQ - Continuous Performance Monitoring and Evaluation

In addition to preventative and regular maintenance of the building and its systems, building managers and owners should develop an IAQ-Energy management plan to monitor the IAQ and the energy efficiency of the building and its systems over time. The IAQ-Energy Management Plan documents how to maintain and improve the building energy use and establishes strategies for reducing energy use while enhancing or maintaining the building IAQ. An IAQ-Energy management plan is an example of a continuous performance monitoring and evaluation technique. This plan helps building operators, managers and owners to track, modify and better understand how to improve or maintain a high quality indoor environment that is healthy, energy efficient and comfortable. It can also assist in the identification, documentation and management of potential IAQ and energy efficiency problems, and help prioritize budgets for maintenance and future modifications (See *Module 4 – Recognizing and Addressing IAQ Problems* for a discussion on other monitoring and evaluative methods). It is estimated that continuous monitoring and analysis can increase a building's energy efficiency by up to 20%[4]. In order to create an IAQ-Energy management plan the following are needed[5]:

1) Designate an Energy Manager

The building owner should designate an individual or individuals to act as the Energy Manager of the building. The energy manager is responsible for ensuring that energy use in the building is minimized without compromising the indoor air quality. The energy manager may be the building owner, an employee (such as a building operator or manager), or a professional consultant/firm retained by the owner. The energy manager should have the following responsibilities:

- Implement the results of IAQ energy audits and measures outlined in the IAQ-Energy Management Plan.
- Evaluate energy efficiency and IAQ of proposed new construction, facility expansion, remodeling, or new equipment purchases.
- Review facility operation and maintenance procedures for optimal energy and IAQ management.
- Adhere to energy management and IAQ building codes and standards.
- Report regularly to management, stakeholders and occupants.

2) Determine if the building has established energy or IAQ targets

The Energy Manager should determine if the building has established energy or IAQ targets based on previous assessments/audits of the building or developed in conjunction with current best practices, standards and codes. Buildings without energy/IAQ targets should undertake an audit in order to develop such targets. The audit should include the building site, envelope, lighting, HVAC systems, domestic water systems, refrigeration, power generation equipment, power supplies, power distribution units, people moving systems and other systems that can affect the building IAQ and energy efficiency. A qualified energy auditor or firm should be hired for this purpose and an audit report should be generated.

[4] Granderson, J., Piette, MA. Rosenblum, B., Hu, L. et al. 2011 Energy Information Handbook: applications for energy efficient buildings operations Lawrence Berkeley National laboratory, LBNL-5272E

[5] This information has been modified from ASHRAE Standard 100-2006

There may be a need to retain both an energy auditor and an IAQ auditor and combine audit results if the individual/firm is not qualified or expert in both.

3) Develop an IAQ-Energy management plan and collect/assess information on building IAQ and energy efficiency performance

An IAQ energy management plan clearly documents how to maintain and improve the building energy efficiency, and establishes strategies for reducing energy use while keeping indoor air quality in perspective. The IAQ energy management plan should be reviewed annually. Twelve months of consecutive data on IAQ issues reported for the building and the net energy consumption data should be compiled (including purchased and exported energy; utility or energy delivery bills; energy meters, IAQ sensors and controls monitored data). Information about the building can also be collected from operations and maintenance forms, as well as the maintenance and custodial staff, repair professionals, and the building occupants (through general and periodic inspections). An IAQ-Energy management plan should have the following components:

- An operation and maintenance plan that includes a review of the following systems: Building Envelope and Site; Domestic Hot Water Systems; HVAC System; Refrigeration Systems; Lighting Systems; Controls Systems; Electric Power Distribution and On-site Generation Systems.
- An energy accounting system to record the energy use and the IAQ during the building's initial year of certification.
- Baseline measurements for the building's IAQ and energy utilization intensity (EUI)
- Annual updates of the building's IAQ/EUI and comparison to the facility's annual IAQ/EUI baseline to establish or assess the trend of performance over time.
- Documentation on any changes to occupancy, hours of operation, production rates and energy using equipment during the year, that would have caused changes in the annual IAQ/EUI measurements compared to the baseline.
- Documentation on the facility's annual energy and IAQ performance goals. Buildings with targets will use the target as the goal. Buildings without a target will have the IAQ energy manager or the energy auditor set a target.
- Reports of energy audits and recommended IAQ and energy efficiency measures (EEMs)
- List of equipment for replacement or repair.

- Contact list of equipment suppliers, manufacturer's local representatives, and energy auditors; Ensure that all equipment is compliant with best practices and standards for IAQ and energy efficiency.
- Documentation (checklists) on lighting schedules and lighting power density, identifying savings from any potential energy efficiency measure.

4) Assess results from the IAQ-Energy management plan in order to integrate results into the building, implement changes and energy efficient measures, and aid in future building decision making. The outcomes of an IAQ-Energy management plan should be:

- Integrated into the overall capital improvement plan for the building to evaluate the costs and benefits of ownership of new and existing equipment and make informed decisions regarding capital expenditures.
- Used to establish ongoing IAQ-Energy Efficiency priorities. A written energy management plan should prioritize the list of energy efficiency measures and specify an implementation timeline.
- Used to create an Implementation Plan if the building does not meet established standards and targets. The plan should include specific goals and energy efficiency measures that will allow the building to comply with best practices, standards and established building targets. Targets should be monitored until they have been met for a minimum of one year.
- Used to create an ongoing written training plan for the building staff on IAQ and energy efficiency measures.
- Used to evaluate the effectiveness and usefulness of the plan itself and make any changes to the plan as needed.

5. Next Steps- Incorporating Energy Efficient IAQ Into Your Existing Building Plan

This module in conjunction with the standards, codes and programs included in Table 3.1 have highlighted the following useful strategies for building managers, operators and owners to consider for improved building energy efficiency and IAQ:

- Hybrid ventilation strategies optimize the use of both natural and mechanical ventilation systems for energy efficiency and IAQ.
- There are many ways in which mechanical indoor air delivery system can be enhanced, using both technological and material advances in system components, or connecting the HVAC system to renewable energy technologies, if possible.
- Economizers, energy recovery systems, high quality filters and sensors/controls can be used to maximize HVAC efficiency at part-load conditions.
- There are many options available to customize air delivery systems to the needs of the building and its occupants.

- If air delivery systems are to be optimized for indoor air quality and energy efficiency the following is needed:
    - Preventative maintenance and cleaning of both the building itself and its HVAC system; ○ Education/information and training of building managers, operators, staff and occupants;
    - An overall strategy to minimize the entry and retention of contaminants and pollutants within the building;
    - Consideration of the building site and building orientation with respect to emissions, noise and artificial/natural landscaping.

All of these considerations should be incorporated into building performance documents such as the IAQ profile and IAQ audit reports.

5.1 Adapting IAQ Profiles and Audit Processes

Previous modules have recommended the development of an IAQ profile and audit of the building. An IAQ profile is a written description of the building structure, function and occupancy that impact the quality of the air inside the building. It provides baseline information of the current status of the air quality in the building that can be used for comparative purposes. The IAQ profile should be an organized set of records, materials and documents that can be referred to when planning for renovations or dealing with issues in the building. The information needed for an IAQ profile is similar to that collected when solving other indoor air quality problems (see *Module 4 – Recognizing and Addressing IAQ Problems* for more information), but includes the entire building as a whole rather than focusing on specific areas where problems were identified.

An IAQ audit uses the baseline information from the IAQ profile and other benchmarking standards, codes and best practices to compare against building IAQ data collected on a regular basis. A list of different benchmarking standards and best practices can be found in Table 3.1 and in Appendix A. Various organizations and departments have developed forms and processes to guide building managers and operators perform an IAQ audit. It is recommended that IAQ profiles and IAQ audits also incorporate energy audit criteria, and features/measurements that specifically combine energy efficiency and IAQ performance. A template for an IAQ audit checklist is provided in Appendix A.

5.2 Adapting other Building Strategies

Other processes and strategies that pertain to the life cycle of the building will need to be adapted to include sections on energy efficient IAQ. These may include:

- Incorporating feasibility studies for hybrid ventilation systems or for new energy efficient HVAC or renewable energy technologies (such as radiant floor heating, solar walls/transpired solar collectors, and geothermal options).
- Tracking the effects of occupancy changes and space planning on building energy efficiency and indoor air quality.

- Updating operating budgets to account for energy efficient components that need to be incorporated into current HVAC systems such as economizers, high efficiency filters, heat recovery systems, etc.
- Updating maintenance budgets to account for preventative and regular maintenance activities.
- Modifying life cycle costing to account for energy efficient retrofits, additions or new projects, alongside adjustments for cost savings and budgets required for preventative maintenance of HVAC systems and the building.
- Planning for improvements as new renewable energy equipment becomes available, or as new advances in indoor air cleaning and filtering technologies become available.
- Development of new metrics, if needed for equipment and overall cost effectiveness and capital expenses.
- Investigating potential sources of funding through green funding initiatives, private or public grants/assistance programs/incentives and building competitions.

5.3 Communicating with Building Occupants

One of the main reasons why building systems have moved towards increased customization is to allow the building occupants to have the ability to control and change their surroundings for improved comfort, productivity, health and overall feeling of well-being. However, this means that building occupants need education and training about best practices that maximize indoor air quality and indoor comfort without compromising the energy efficiency or the functionality of the building mechanical or air delivery systems. Building occupants also need training about the equipment being used (i.e. control panels, thermostats) so that they do not compromise the operation of the building systems (*Module 4 – Recognizing and Adressing IAQ Problems* presents more strategies for dealing with occupant complaints and feedback).

The failure to maintain acceptable air indoor quality can have major consequences on human health, reduced productivity and absenteeism, accelerated deterioration of the building and its reputation, strained landlord/tenant or employer/employee relations. All of these consequences highlight the importance of continuous performance monitoring and evaluation of buildings to help mitigate possible problems for building operators, managers and owners.

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