

Final Scientific/Technical Report

US Department of Energy

National Energy Technology Laboratory, Buildings and Efficiency Technology Division

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University of Nebraska – Lincoln, 113 NH, Lincoln, NE 68588-0500

Project Title:

Veterans Commissioning Training Program for Commercial Healthcare Facilities

Project Duration:

7/7/2010 - 7/31/2013

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Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the Department of Energy.

Executive Summary

This project was designed to develop a building energy training curriculum, with hopes for creating immediate, long-term job opportunities for returning Iraq and Afghanistan veterans as energy commissioning agents within both public and private sectors. As part of this proposed effort, an online version of the curricula were developed in part using a modified version of the Association of Energy Engineers (AEE) Certified Building Commissioning Professional program. Case studies utilizing building information modeling (BIM) data from actual retro-commissioning projects and 3D gaming platform were developed as part of the curriculum. In addition to using materials from existing literature, the PIs also conducted scientific-based research on energy retrofitting related to building envelopes using numerical simulation approach. And the research findings and recommendation were incorporated in the developed curriculum.

Currently, there are a lack of scientific-based guidance on envelope retrofitting practice. Many retrofitting practices were based on experiences, and are limited by the lack of scientific evidence. Existing retrofitting training material have limitations due to this missing piece.

We have succeeded in producing some scientific evidence to guide and provide solutions to some building envelope design and retrofitting. The results from some of our research using computational fluid dynamics have demonstrated the feasibility of using our recommended solutions. Research results and findings were disseminated to the research and industry communities through conference papers (Appendix B) and presentations (Appendix C), and some results and findings were incorporated into the developed training curriculum (Appendix A).

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Objective(s)

- To create a training curriculum for the development of an energy commissioning workforce to ensure that new and existing U.S. buildings reduce energy use and related environmental impacts use while improving occupant comfort and safety.
- To create immediate, long-term job opportunities for returning veterans as energy commissioning agents within both public and private sectors.
- To provide specialty training in building envelope retro-commissioning to ensure a competitive niche for trainees entering the job market.
- To provide scientific evidence for guiding building envelope retrofitting practice.
- To incorporate scientific-based retrofitting recommendations and findings in the developed curriculum.

Scope of Work

An energy commissioning training curriculum will be developed using a modified version of the Association of Energy Engineers (AEE) Certified Building Commissioning Professional (CBCP) program and validated using actual commissioning projects and numerical simulations. The training program will be developed to prepare 'graduates' for careers as commissioning agents/auditors in all major building markets with specialized training in the 're/retro' commissioning of building facilities. The program will include a balance of distance/online education, classroom/field instruction and a nationally recognized certification exam to maximize training effectiveness and minimize program costs. This training will primarily serve returning veterans entering the U.S. job market and will be sustained beyond the funding period of this grant through partnerships with the VA, AEE, U.S. Department of Energy (DOE) Hospital Energy Alliance (HEA) and the private sector.

As part of this proposed effort, an online version of the curricula were developed in part using a modified version of the Association of Energy Engineers (AEE) Certified Building Commissioning Professional program. Case studies utilizing building information modeling (BIM) data from actual retro-commissioning projects and 3D gaming platform were developed as part of the curriculum.

In addition to using materials from existing literature, the PIs also conducted scientific-based research on energy retrofitting related to building envelopes using numerical simulation approach.

Project Activities/Tasks

Phase 1 (7/7/2010 – 8/31/2012)

1. Literature review
2. Integration Plan
3. Curricula Deficiency/Developmental Needs Analysis
4. Software Assessment
5. IT platform Determination
6. Scientific Research on Building Envelope Design and Retrofitting Methods

Phase 2 (9/1/2012 – 7/31/2013)

7. Curriculum Development
8. Consolidation of Training Materials
9. Certification and Accreditation Plan
10. 3D Virtual Training Case Development

Course Contents (see Appendix A for details)

MODULE 1: INTRODUCTION TO BUILDING COMMISSIONING**MODULE 2: TOTAL BUILDING COMMISSIONING****MODULE 3: RE/RETRO-COMMISSIONING****MODULE 4: HEALTHCARE FACILITIES COMMISSIONING****MODULE 5: BUILDING ENVELOPE RETROFITTING****MODULE 6: 'VIRTUAL' COMMISSIONING CASE-STUDIES**

Commissioning is the process of ensuring that building systems are designed, installed, functionally tested, and capable of being operated and maintained according to the owner's operational needs. Commissioning also can restore existing buildings to high productivity through renovation, upgrade and 'tune-up' of existing systems. Course content is developed to provide comprehensive training on all aspects of building commissioning, including project scheduling, roles and responsibilities of the project team, new building commissioning, re/retro commissioning of existing buildings, system by system commissioning requirements, test and balance (T&B) verification procedures, the LEED rating system, project economic analysis, building code issues, and commissioning tools and technologies. A detailed lesson plan was developed according to the topics of the course outline below.

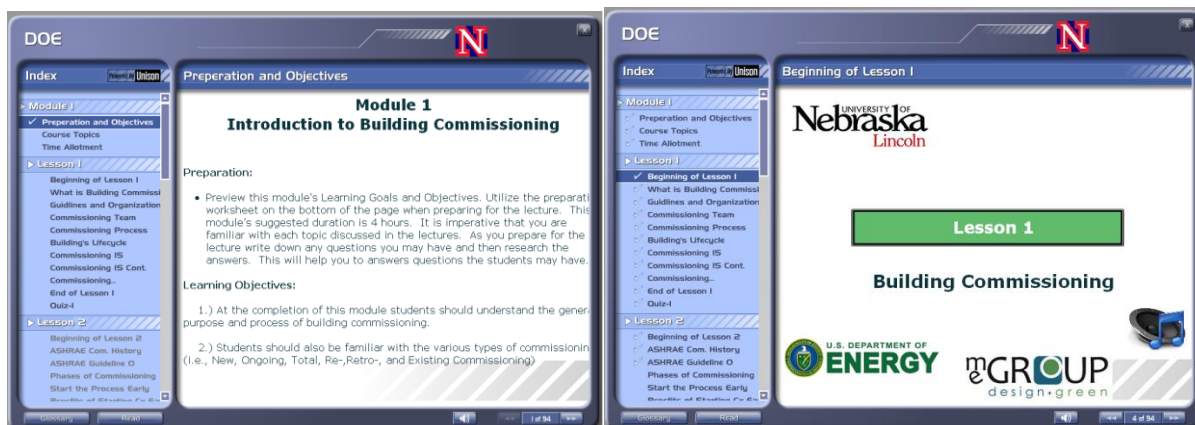


Figure 1. Screenshots of the online course modules.

MODULE 1: INTRODUCTION TO BUILDING COMMISSIONING

- What is Building Commissioning?
- Why We Need Commissioning - Aligning the Owner, Designer, Contractor, and Operator
 - o Introduction to energy efficiency in commercial buildings
 - o Benefits of energy efficiency and commissioning
 - o Valuing technology-specific energy efficiency improvements

- Typical Project Schedule - Commissioning Perspective
 - o Design-bid-build-operate
 - o Bid-design-build-operate
- The Project Team

MODULE 2: TOTAL BUILDING COMMISSIONING

- What Needs to Be Commissioned and How Are These Systems Commissioned?
 - o Structural systems
 - o Envelope systems
 - o Interior systems
 - o Conveying systems
 - o Environmental and energy systems (lighting/M/E/P)
 - o Communications systems
 - o Site and landscape systems
 - o Protective systems
- Commissioning Tools and advanced energy technologies
 - o Heating systems
 - o Cooling systems
 - o Refrigeration systems
 - o Ventilation systems
 - o Moisture control systems
 - o Hot water systems
 - o Lighting systems
 - o Sensors and energy management systems
 - o Renewable energy systems
 - o Indoor air quality
- Commissioning Guidelines and Benchmarking energy performance
 - o Benchmarking energy performances of systems, components, and whole buildings
 - o Methods to improve energy performances
 - o Testing, adjusting, balancing and verification
- Building an energy performance awareness program
- Improving integration of building systems
 - o Identifying potential building system synergies (e.g. energy recovery systems)
 - o Advanced technologies for synergistic benefit
- Best practices maintenance of building systems and components
 - o Fault detection (automatic and manual)
 - o Correct maintenance procedures and quality assurance techniques
 - o Sensors and energy management systems
- Economic Analysis and Procurement
 - o Typical least cost operational adjustments to improve energy efficiency

- Commissioning and the LEED Rating System
- Commissioning and the Federal Government

MODULE 3: RE/RETRO-COMMISSIONING

- Concept / Programming Phase Objectives
 - o Retro-commissioning, recommissioning, and building tune-ups
 - o Developing, planning and communicating
 - o Defining the project scope
 - o Budgeting
 - o Choosing the commissioning professional for retro-commissioning
 - o Reviewing and updating building
 - o Commissioning plan
 - o Team meeting
 - o Original design intent vs. current use
 - o Building codes
- Investigation Phase Objectives
 - o Communication
 - o Occupant impact
 - o Operation and maintenance
 - o Building automation system & trend logs
 - o Commissioning documents
 - o Retesting and remonitoring
 - o Training
- Project Turnover Objectives
 - o Close-out Documents
 - o Final Report

MODULE 4: HEALTHCARE FACILITIES

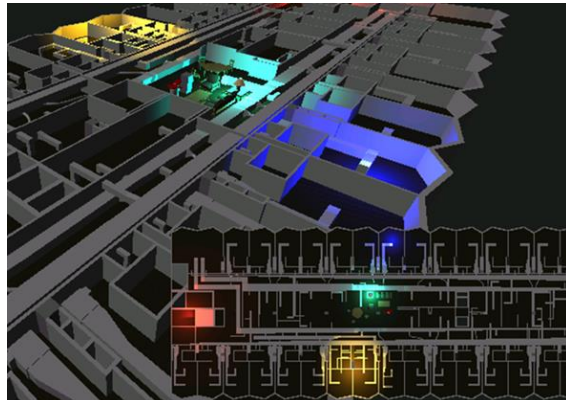
- Hospital Facilities
 - o Air quality and infection control
- Infection sources and control measures
- Air movement
- Temperature and humidity
- Pressure relationships and ventilation
 - o Specific design criteria
- Surgery and critical care
- Nursing
- Ancillary
- Administration
- Diagnostic and treatment
- Service and supply
 - o Continuity of operations
- Outpatient Healthcare Facilities
 - o Diagnostic Clinics

o Treatment Clinics

MODULE 5: BUILDING ENVELOPE RETROFITTING

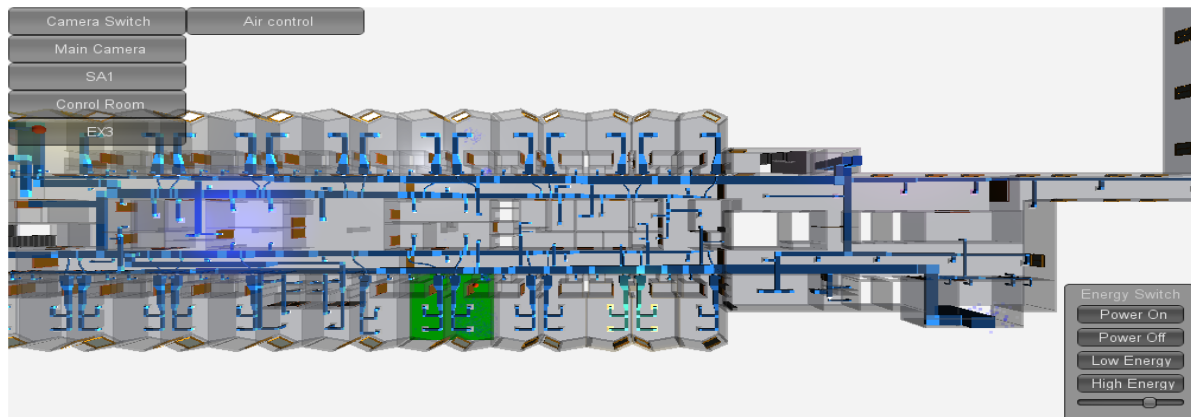
- Introduction
- Energy-efficient Building Envelope Design
- Thermal Insulation and Airtightness of the Building Envelope

MODULE 6: 'VIRTUAL' COMMISSIONING CASE-STUDIES



Negative ('Pandemic') Mode		
15-Dec-09 SA1	Ward supply air	2,754 Duct traverse. Decreased VFD to ~30Hz
SA2	Lobby supply air	2,072 (12/14 measurement)
EX1	South exhaust air	-2,379 Duct traverse
EX2	North exhaust air	-4,333 Duct traverse
EX3	Lobby exhaust air	-1,326 (12/14 measurement)
		-3,212 Ward is (very) negative to adjacent zones
		2.0 OA ACH ≥ 2.0
		3.3 Total ACH < 4.0
S317	Isolation room 1	100% OA (no return)
SA1	Anteroom supply air	0 Flow hood
SA2	Patient room supply air	51 Flow hood
EX1	Anteroom exhaust air	-33 Flow hood
EX2	Bathroom exhaust air	-38 Flow hood
EX3	Patient room exhaust air	-128 Flow hood
		-148 Room is ≥50cfm negative relative to corridor
		1.3 OA ACH < 4.0
		5.1 Total ACH < 12.0

Web-based 3D Curriculum | hospital



Camera Switch Air control

Main Camera

SA1

Control Room

EX3

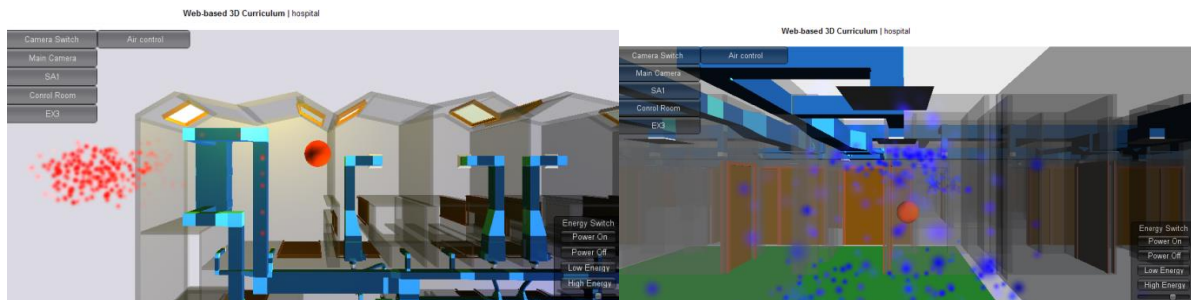
Energy Switch

Power On

Power Off

Low Energy

High Energy



Web-based 3D Curriculum | hospital

Camera Switch Air control

Main Camera

SA1

Control Room

EX3

Energy Switch

Power On

Power Off

Low Energy

High Energy

Figure 2: Snapshots of the 3D Virtual Training Case

Websites: <http://bcvs.unl.edu/Hospital-2012-Mar-02.html>

<http://bcvs.unl.edu/buildingtest01.html>

An actual retro-commissioning project at VA medical centers in Florida provide real-world case studies for the 'virtual' commissioning of healthcare facilities located in hot-humid climates (IECC region 2). Provided on a building information modeling (BIM) platform, teams of participants will be challenged with producing real Cx deliverables, and, to develop practical solutions to typical Cx problems during classroom instruction. Student teams will complete a virtual commissioning project using one or more of these three projects, prepare a comprehensive commissioning report and present findings to the owner's representatives (e.g. instructor and students) at the conclusion of each session to test their technical competencies, critical thinking ability, and their oral and written communication skills.

The case study is a retro-commissioning project in a 120-bed, 50,000sf in-patient ward currently underway at the Malcolm Randall VAMC, Gainesville, Florida. This facility was constructed in 1979 and has undergone several modifications since. In this exercise, as-built drawings, test and balancing (T&B) reports and other documentation will be intentionally incomplete (as often exists in actual projects), and will thus challenge students to develop a comprehensive pre-commissioning assessment plan. In addition, students will have to justify those systems that can be retro-commissioned, and those that should be upgraded or replaced.

The first five (5) modules, were developed in an interactive, Internet-based curricula conducive to distance education. Training Modules 1-5 were written in HTML format and will be compatible across all web browsers, meaning virtually any authenticated user (e.g. registered veteran) with Internet access will be able to access the online segment of the training program from their desktop or laptop. Each training module will contain descriptive text, graphics, streaming video clips and instructor 'voice-over', providing an interactive self-study experience.

Upon completion of each on-line training module, the participants will be asked to complete a short quiz. These will be simple quizzes, generally consisting of multiple-choice or true-false questions. Correct answers will be provided upon completion to reinforce key training points, and, to prepare students for the 4-hour certification exam at the conclusion of the 3-day classroom/field training session to follow. The performances on the quizzes will provide good evidence of the quality of instruction in the online training module. In addition, results of the quizzes will be automatically sent to AEE curricula development staff. Modifications to the instruction materials will be made if information has not been properly conveyed through the training modules.

Module 6 was completed as part of classroom sessions following the distance education segment (Modules 1-5). Classroom instruction will include a review of modules 1-5 followed by a case study session for the 'virtual' commissioning of healthcare facilities located in hot-humid climates (IECC region 2). The training materials will be hosted on a developmental website to

provide DOE instant 24/7 access to review on-going curricula development for appropriateness and completeness.

Research Components

In addition to the curriculum module development, one important piece of the project is the research components, which provided scientific contributions to the project. The research components of this project were on three areas: 1) 3D virtual training environment; 2) Building attic study; 3) self-ventilated cavity wall systems; and 4) Energy loss through recessed lighting fixtures. One journal papers and three conference papers were published from the partial support of this grant. This grant also supported travels to three international conferences to disseminate the research results.

1. Developing 3D Virtual Training Platform

Jiang, L.1, Shen, Z., Grosskopf, K., and Berryman, C. (2012). "A BIM based interactive 3D web environment for energy retrofit training". Construction Research Congress 2012, May 22-24, Lafayette, IN, 1212-1221

A web-based 3D game project was presented in this paper to demonstrate the process of using building information modeling (BIM) to create an interactive 3D on-line 'Green' training environment. The system architecture, the implementation process and major components of this virtual training environment were discussed. Existing studies on BIM-based collaborations mainly focused on local-file-sharing approach using proprietary applications. Limited research focused on using BIM as an online gaming platform to create a web browser-based interactive 3D virtual environment for collaboration, learning and/or training. The gap was partially caused by the lack of understanding how to implement a BIM-based game in web browser environment. In this paper, the authors provided an implementation example using a hospital BIM model to create an interactive web-based 3D BIM game environment to allow users to visualize and interact with the BIM components using regular web browsers. The intention of this project is to create a proprietary-independent training environment to conduct energy re-commissioning trainings for hospital facility management staff. This virtual BIM environment can potentially be customized for engineering student learning and project collaborations as well. The conclusion was that current BIM and game technology are mature enough to allow us to create serious web-based interactive learning/training virtual environment. The successful integration of BIM and web browsers paved the way for many learning and training applications, which need built-environment as context.

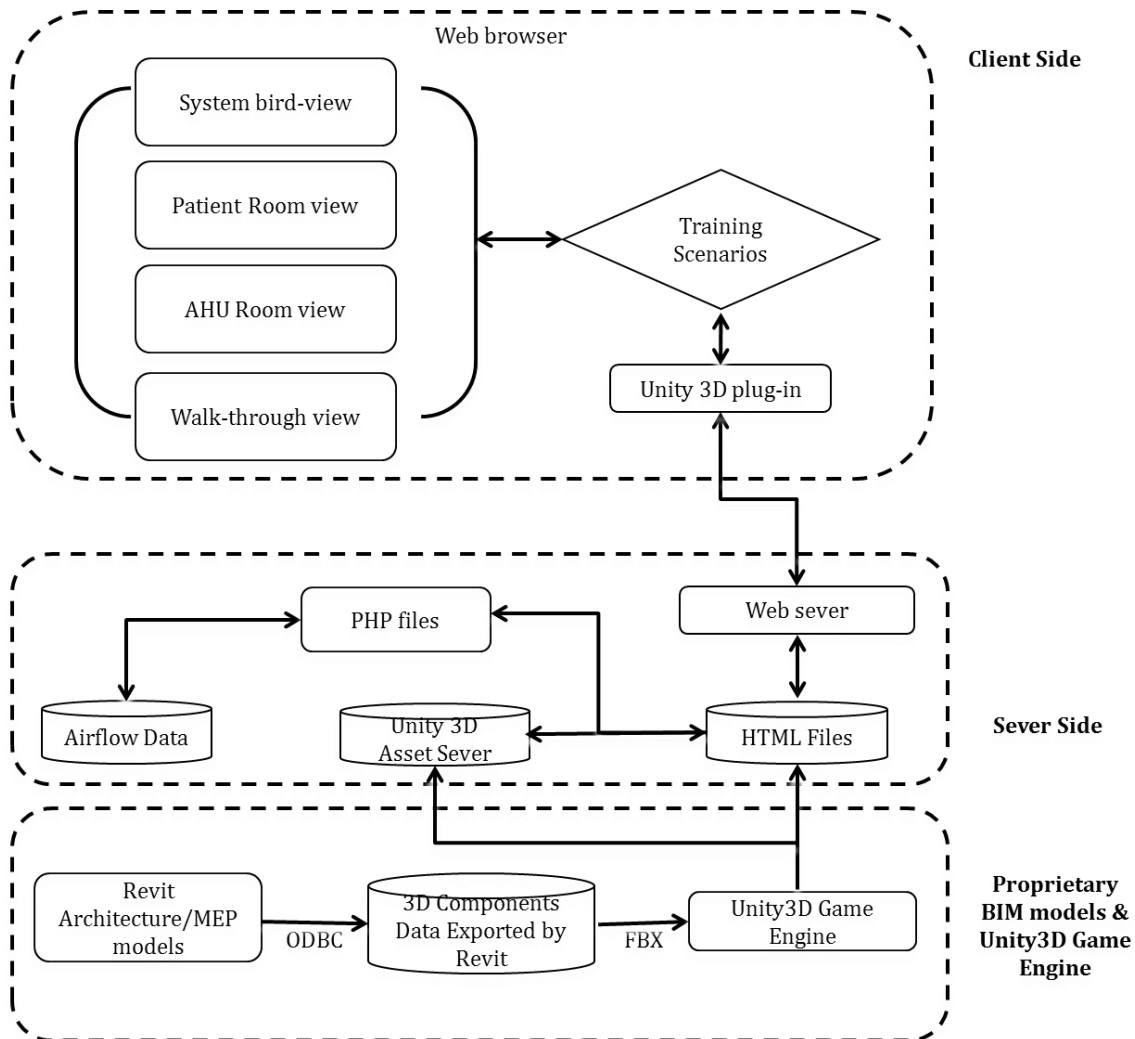
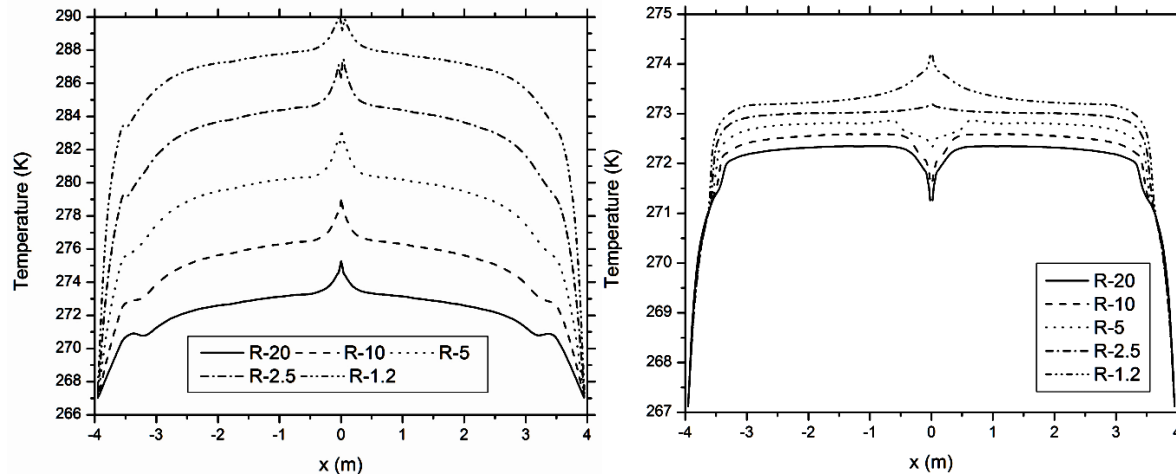


Figure 3 .The architecture of the implemented game environment

2. Attic Design and Retrofitting Study

Wang, S., Shen, Z. *, and Gu, L. (2012). "Numerical simulation of buoyancy-driven turbulent ventilation in attic space under winter conditions" *Journal of Energy and Buildings*. 47, 360–368

Attic design and construction have significant impacts on residential buildings' energy performance. In order to understand how passive ventilation rates affect ridge-vent attic's performance, a two dimensional steady-state finite volume model is employed to simulate the buoyancy-driven turbulent ventilation and heat transfer in a triangular attic space of a gable-roof residential building under winter conditions



The modeled attic has a pitch of 5/12 and a passive ventilation system, consisting of continuous ridge and soffit vents. The v2f model is used to analyze the turbulent air flow and natural convection heat transfer inside the attic. The effects of ambient air temperature, vent size, and ceiling insulation on heating load and ice dam formation are investigated. The thermal performance of the vented attic is compared with a sealed attic as well. The simulation results reveal that symmetrical air flow patterns exist in a vented attic, in contrast to the asymmetrical air flow patterns found in a sealed attic. In addition, it is suggested that increasing vent size results in higher ventilation air flow rate but barely affects the attic heating load, and that both sufficient ventilation and insulation are needed to ensure the proper functions of the attic and its energy efficiency.

3. Self-ventilated cavity wall systems

Lin, S., Shen, Z., Grosskopf, K. (2013) "Investigating the potential of self-cooling cavity wall system in reducing buildings' summer peak cooling load". The Asian Conference on Sustainability, Energy & the Environment (ACSEE) 2013, Osaka, Japan, June 6-9

Cavity wall is a common type of building wall system in both commercial and residential buildings in the US. Cavity walls are typically formed by an exterior layer of brick or block (4 to 8 inch thick), a middle layer of air (2 to 6 inch thick cavity), and an interior layer of structural/insulation material. Fig. 1 illustrates cross-sections of some typical cavity walls. The main function of the wall cavity is to discharge unwelcome water/moisture through very small wipe holes, which connect the cavity with exterior environment.

In this project, we proposed a novel utilization of the existing cavity wall, i.e., converting it into a self-cooling cavity wall (SCCW). CCW is created by adding coupled exterior wall openings (air inlets and outlets through controlled louvers) on the exterior veneer of cavity-walls. The controlled air inlets / outlets will create a naturally ventilated cavity wall. The notable advantage of this SCCW system is the conversion can be done with little modification of the existing design or existing buildings. The conversion is easy to do for both new and existing cavity wall buildings. It is

expected that the SCCW system will substantially reduce the summer heat-flux through cavity walls, especially during the peak cooling-load time.

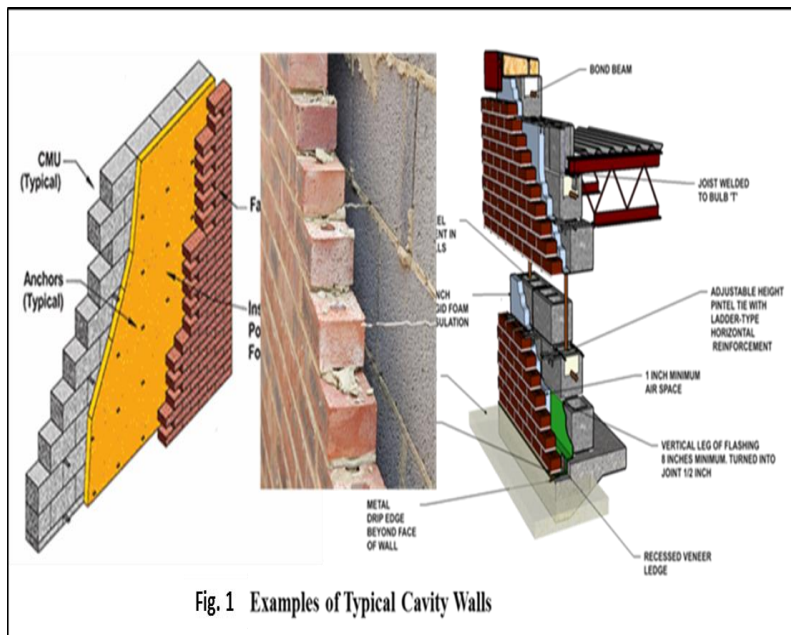


Fig. 1 Examples of Typical Cavity Walls

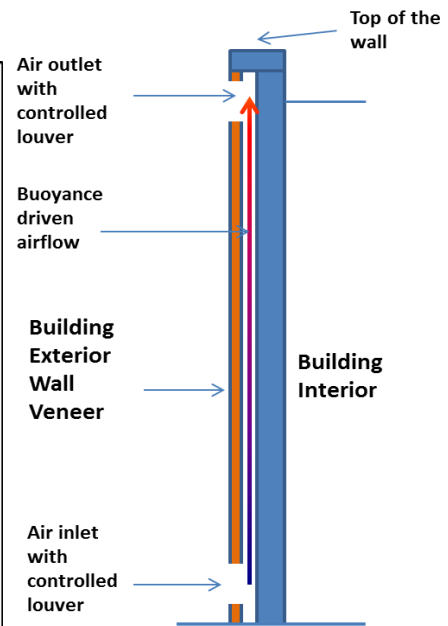


Fig. 2 Schematic SCCW system

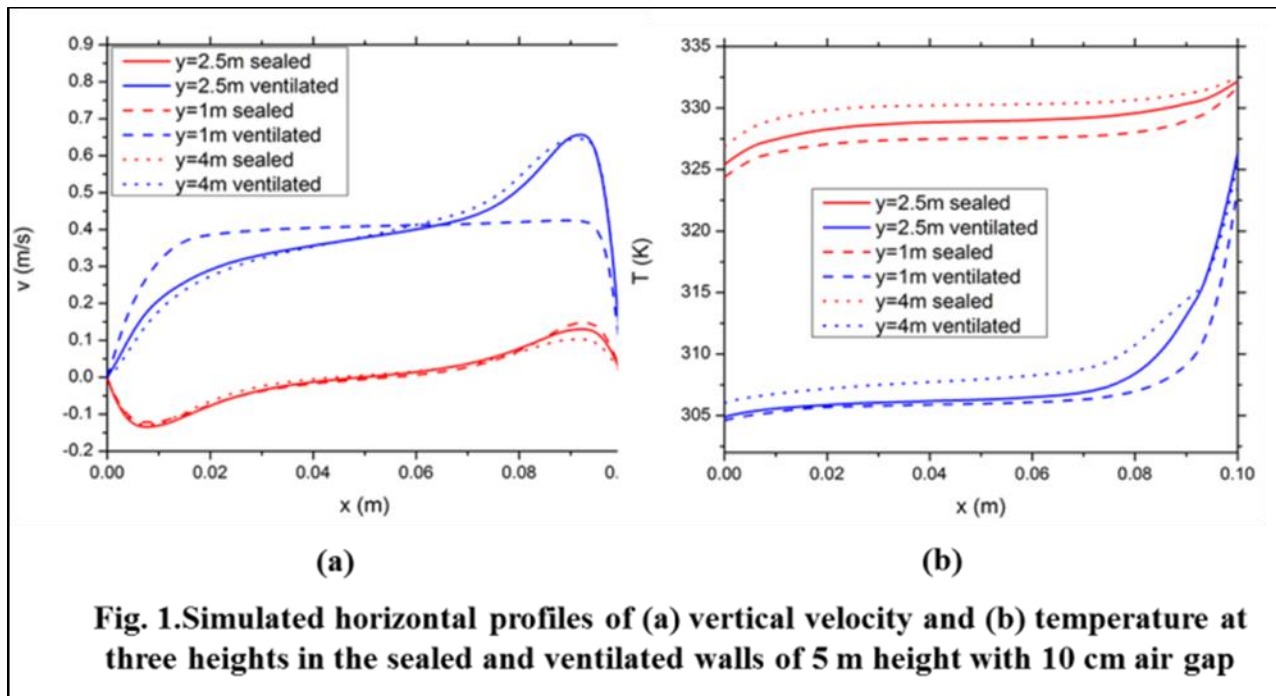


Fig. 1. Simulated horizontal profiles of (a) vertical velocity and (b) temperature at three heights in the sealed and ventilated walls of 5 m height with 10 cm air gap

SCCW utilizes buoyance-driven ventilation caused by irradiance-heated vertical walls to discharge the accumulated heat inside the cavity wall and reduce the wall heat-flux. Controlled opening size and layout are associated with the efficiency of building cooling load reductions. The key for designing energy-efficient SCCW for existing cavity wall is to determine the optimal opening sizes and locations of inlets and outlets.

Our preliminary evaluation (Fig. 3 and Table 1) has demonstrated that the effect of the SCCW is very significant in terms of reducing heat flux through walls. In the cases in Fig. 3, the naturally ventilated 10-cm-wide cavity layer in the 5-m tall wall is equivalent to adding R-60 insulation in summer time, which is well-above the sealed cavity, which equivalent to R-8. Table 1 summarized a simulated performance of a 5-cm-wide-cavity masonry wall during the worst summer peak-time conditions. It indicates that a 5-cm masonry wall cavity, when ventilated, can achieve insulation equivalents of R39 to R47 depending on the cavity heights. It is clear that the buoyance-driven cavity ventilation is a very promising solution to reducing summer peak-time cooling load.

In addition to reductions in solar heat flux, the air space will also reduce vapor pressure which tends to drive moisture into the wall and cause mold and structural deterioration. However, during winter time, when the convection is not desired, the air inlet and outlet louvers installed on the walls will be closed to avoid increasing heating load.

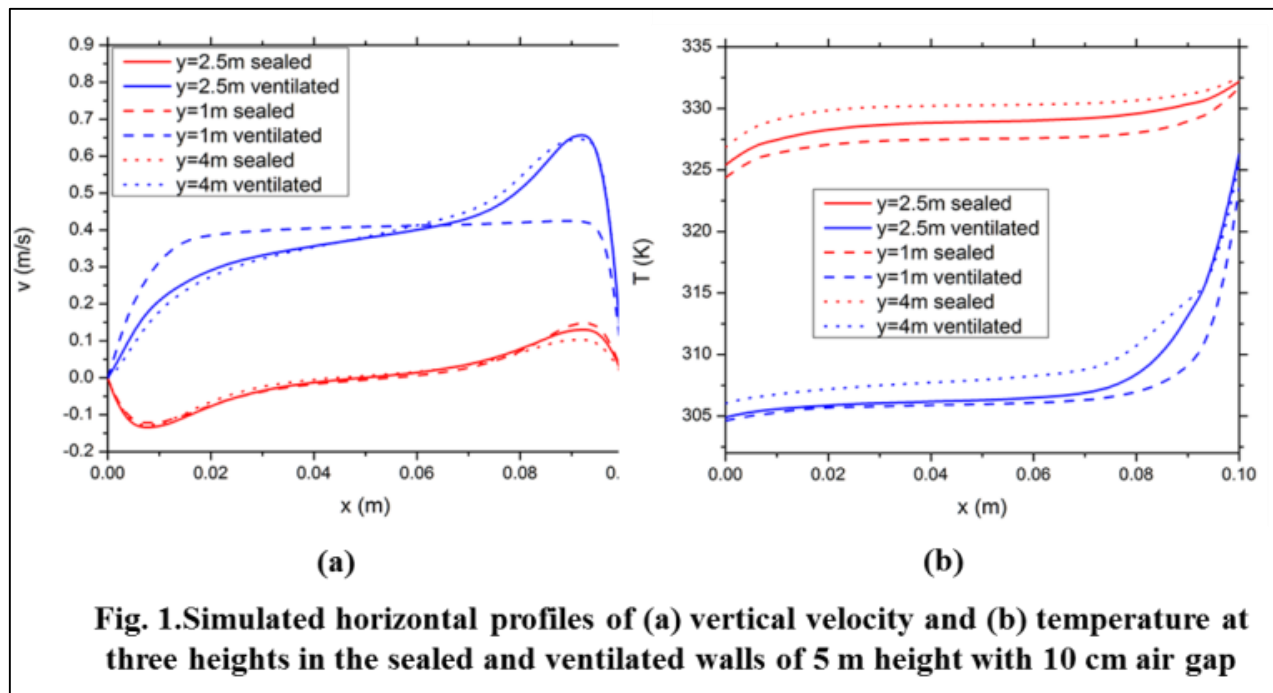


Table 1. Numerical results of ventilated walls

Wall height (m)	Cavity thickness (cm)	Mass flow rate (kg/m s)	Cooling load (W/m)	R-value of the air channel
5	5	0.02906	15.36	47.44
7.5	5	0.03689	24.67	42.80
10	5	0.04334	34.88	39.06

In the project, the PI conducted preliminary 2D and 3D parametric studies to investigate how relevant SCCW system parameters affect the wall-heat-flux, especially during peak cooling load time. Expected major parameters include, not limit to, cavity thickness, cavity height, inlet/outlet the number, size and layout of inlets/outlets, veneer material, and different weather-induced boundary conditions. Both numerical and experimental approaches will be employed to

investigate different SCCW configurations of the main parameters. The findings from this parametric study can be used: 1) to provide quantitative guidance for energy retrofitting of cavity-wall buildings; 2) to guide the design of new buildings and envelope products, such as sidings with vertical channels to enhance the self-cooling effects.

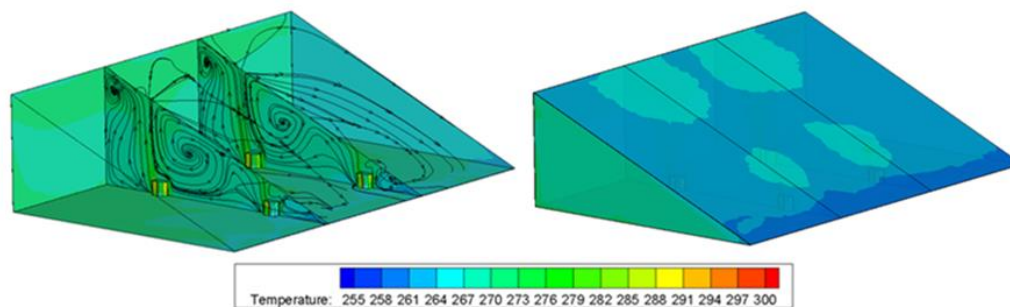
Based on the preliminary evaluation, we can expect significant and wide summer cooling-load savings as the results of this research. This solution is especially helpful for reducing peak-time cooling load due to the solar chimney effect. The peak-time cooling load reduction can be significant savings for many commercial building users/owners. The outcomes from this research are expected to be equally instrumental to energy-efficient designs of new buildings and retrofitting of existing buildings.

4. Energy loss through recessed lighting fixtures

Na, R., Lin, S., Shen, Z., Gu, L., Grosskopf, K. (2013). "Impact of air leakage through recessed lighting fixtures on the energy performance of residential buildings - a case study". Central Europe towards Sustainable Building (CESB13), Prague, CZ, June 26-28, 2013

In this paper we mainly quantify the impact of envelope air leakage through recessed lighting fixtures. Our findings indicate this type of leakage is very significant, and can substantially reduce the energy performance of building envelopes.

The actual energy performance of buildings depends on not only the design criteria but also on the construction quality of buildings. Many design assumptions can be invalidated by unexpected construction quality issues, and lead to large variations between the designed performance and the constructed performance. Though important, very limited research, especially quantitative study, is found on evaluating the impact of construction quality issues on building energy performance. In this paper the construction quality issues of residential buildings in the United States is discussed, along with reviews of building envelope related research. A case study on residential attic construction is presented to illustrate how construction quality affects the energy performance of attics.



The case study utilized 3D computational fluid dynamics to simulate air leakage issues in recessed lighting using different boundary conditions. The results of the case study suggest that some seemingly insignificant construction quality issue can cause significant increase in energy consumption of residential buildings. The paper provides scientific evidence to help residential construction industry to improve the construction quality of residential buildings in the United States.

Appendix A: Developed Curriculum Modules

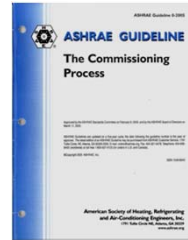
LECTURE 1

Building Commissioning

What is Building Commissioning?

The Commissioning Process is a quality-oriented process for achieving, verifying, and documenting that the performance of facilities, system, and assemblies meets defined objectives and criteria.

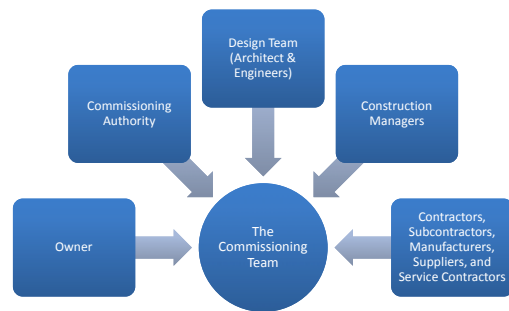
~ASHRAE Guideline 0-2005



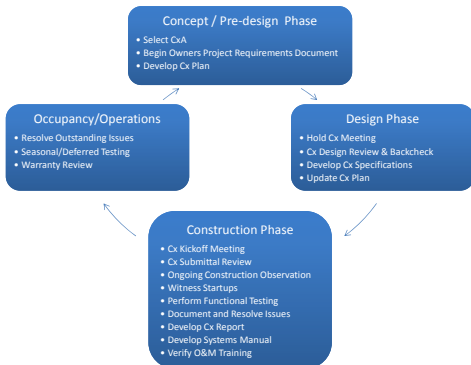
Guidelines and Supporting Organizations

- ASHRAE Guideline 0-2005 (the Commissioning Process)
- ASHRAE Guideline 1.1-2007 – HVAC&R Technical Requirements for the Commissioning Process
- USGBC LEED Fundamental and Enhanced Commissioning Requirements
- ACG Commissioning Guideline (AABC Cx)
- SMACNA HVAC Systems Commissioning Manual
- Building Commissioning Association Guidelines on New and Existing Buildings
- National Institute of Building Sciences Guideline 3-2006 – Exterior Envelope Technical Requirements for The Commissioning Process
- NEBB Procedural Standards for Whole Building Systems Commissioning of New Construction
- NEBB Procedural Standards for Retro-Commissioning of Existing Buildings

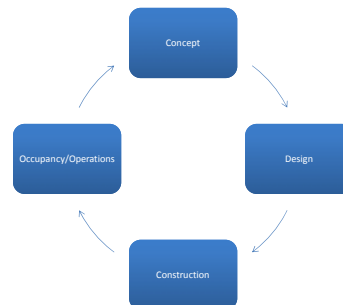
The Commissioning Team



The Commissioning Process



Building's Lifecycle and Commissioning: Problems



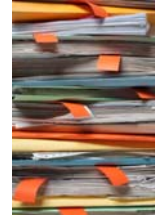
Commissioning IS

- Communication process
- Systematic and Documented Validation
 - Validation of Owners Requirements for the facility
 - Validation that the Design meets Owners needs
 - Validation that installation meets design
 - Validation that installation meets industry standards and code
 - Validation that final performance meets design requirements and owners project requirements
 - Validation that owner receives training and all documentation to support future operations and maintenance efforts.



Commissioning IS

- Documenting the Owners needs
- Documenting the design teams reasoning and decisions
- Conducting quality peer reviews during design
- Defining, specifying, planning and verifying the checkout, start-up, and functional testing of the construction
- Increased coordination and integration
- Making sure systems work efficiently
- Improving the owners documentation and training



Commissioning ...

- Can NOT make up for ill-conceived project objectives and expectations
- Can NOT make up for an inadequate design and/or construction budget
- Can NOT design a building or systems in lieu of the design professionals of record
- Can NOT Construction a building in lieu of the contractors of record
- Does NOT repair major problems and deficiencies with systems or equipment
- Does NOT Operate or maintain a building
- Is not always able to correct project-long problems through last-minute interventions at the end of construction



LECTURE 2

The Commissioning Process

ASHRAE Commissioning History

American Society of Heating, Refrigerating, and Air Conditioning Engineers



- 1982 – Committee formed to document best practices (O&M) for achieving facilities that perform according to the Owner’s Project Requirements (OPR)
- 1989 – Guideline 1 – 1989
- 1996 Guideline 1 – 1996 (Draft Revisions 2006)
- 2005 – Guideline 0 – 2005 – The Commissioning Processing Guideline 0 – Integral part of National Institute of Building Standards
- Guideline 1 – 2007-Technical Aspects of Cx MEP Systems

ASHRAE Guideline 0

- Document focuses on establishing the intent for each phase of the project
 - Description of Process
 - Requirements for acceptance
 - Requirements for documentation
 - Requirements for training
- Actual technical Cx guidelines for each trade are established elsewhere



Phases of Commissioning



- Four phases to the New Building Cx process
- Each phase corresponds to a major element of the new construction process

Start the Process Early

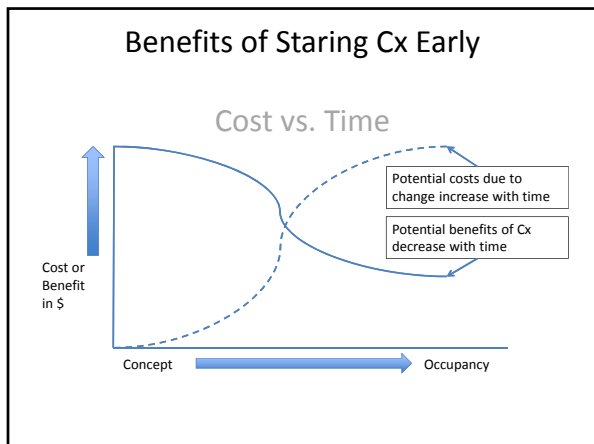
- Emphasis is placed on documenting Owner’s Project Requirements (OPR) at inception
- If this does not happen at inception, then the process should capture the OPR information when the Cx process begins
- Establish scope, roles, and responsibilities
- Set the stage for Cx by communicating a plan

Benefits of Starting Cx Early

- Contractor and Designers have advance notice of Cx activities and requirements
- Commissioning Authority (CA) has adequate time to develop material (plans, tests)
- Culture of Cx has time to “sink in” with the team
 - Do it right the first time
 - Find and correct problems early
 - Test systems to ensure performance
- Less chance of developing a confrontational atmosphere



“Suddenly, a heated exchange took place between the King and the moat contractor”



- ### Pre-design Commissioning Efforts
- Owner typically develops RFP for Cx
 - Cx Agent responds with detail re: scope, hours, fees, tasks and limitations
 - This occurs prior to hiring A/E firm if possible or after design development at the latest
 - Cx Agent develops outline description of roles, responsibilities, and deliverables of the design team relative to Cx

- ### The Commissioning Process
-
- ```

 graph LR
 A[Pre-design] --> B[Design]
 B --> C[Construction]
 C --> D[Occupancy/Operation]

```
- Pre-design Phase
    - Cx Agent helps create the OPR
      - Facilitates Workshop
      - Reviews criteria from a Cx Perspective
    - Cx Agent formulates Design Cx Plan
    - Cx Agent communicates the overall Cx process

- ### The Commissioning Process
- 
- ```

    graph LR
      A[Pre-design] --> B[Design]
      B --> C[Construction]
      C --> D[Occupancy/Operation]
  
```
- Role of the A/E
 - Design team begins formulating systems, concepts and BOD
 - Document owner's required design and operational criteria
 - Establish design criteria, systems description, outline specifications
 - Role of the Owner
 - Provide design and operational criteria
 - Participate in creation of OPR
 - Make decisions with regard to scope of Cx
 - Role of CM/Contractors
 - Review constructability, budget and schedule

- ### The Commissioning Process
-
- ```

 graph LR
 A[Pre-design] --> B[Design]
 B --> C[Construction]
 C --> D[Occupancy/Operation]

```
- Design Phase
    - Basis of Design (BOD) is transformed into construction documents (drawings and specifications)
  - Cx Goals
    - Cx is planned, specified, and communicated
    - Ensure design, reflects OPR via Peer Viewed
  - Cx Agent involved in multiple design submissions and reviews
    - Design development (35%), 50% CDs, 95% CDs, bid set
  - Coordination of overall Cx Effort
    - Schedule and chair periodic meetings
    - Communicate updates
  - Develop the Commissioning Specifications and draft Functional Tests
  - Cx plan for construction

- ### The Commissioning Process
- 
- ```

    graph LR
      A[Pre-design] --> B[Design]
      B --> C[Construction]
      C --> D[Occupancy/Operation]
  
```
- Role of the A/E
 - Produce Construction Documents
 - Incorporate CA comments into design
 - Create and update BOD
 - Role of the Owner
 - Makes decisions relating budget constraints to program and infrastructure needs
 - Role of CM/Contractors
 - Constructability and schedule reviews
 - Smart Value Engineering (without sacrificing value)

The Commissioning Process

```

    graph LR
      A[Predesign] --> B[Design]
      B --> C[Construction]
      C --> D[Occupancy/Operation]
      style B fill:#90EE90
  
```

- Cx Plan for Construction phase
 - Systems and equipment to be commissioned
 - Team responsibilities and communication protocols
 - Pre-functional checklists drafted
 - Process for development and execution of Functional Tests
 - Functional test drafted
 - O&M documentation and training requirements

The Commissioning Process

```

    graph LR
      A[Predesign] --> B[Design]
      B --> C[Construction]
      C --> D[Occupancy/Operation]
      style B fill:#90EE90
  
```

- Construction Document (CD) submission review – 50% and 95%
- Commissioning facilitation
- Energy efficiency
- Control system strategies
- O&M feasibility
- IAQ
- Environmental Sustainability
- Design intent
- Coordination
- Life-cycle costs
- Specifications:
 - O&M documentation
 - Training
 - Commissioning requirements
- Engineering assumptions
- Controls and TAB specifications review

The Commissioning Process

```

    graph LR
      A[Predesign] --> B[Design]
      B --> C[Construction]
      C --> D[Occupancy/Operation]
      style C fill:#90EE90
  
```

- Construction Phase
 - Owner selects Contractor to build project
 - Contractor builds project using construction documents
 - Systems are commissioned
 - Owner is trained and takes possession of project

The Commissioning Process

```

    graph LR
      A[Predesign] --> B[Design]
      B --> C[Construction]
      C --> D[Occupancy/Operation]
      style C fill:#90EE90
  
```

- Coordination of overall CX effort
 - Kick-off meeting to establish roles and responsibilities
 - Schedule and chair CX meetings
 - Communicate updates
- Adjust CX plan for Construction Impact
 - Incorporate information gathered at kick-off meeting
 - Finalize Functional testing procedures (described later)
 - Detailed CX schedule

The Commissioning Process

```

    graph LR
      A[Predesign] --> B[Design]
      B --> C[Construction]
      C --> D[Occupancy/Operation]
      style C fill:#90EE90
  
```

- CX Goals
 - Ensure that building systems are installed, started, tested and turned-over per design intent (OPR and BOD)
- Role of the CA
 - Coordinate, direct and document overall CX effort
 - Review submittals and conduct site visits
 - Finalize, implement and track Pre-functional checklists and Functional Tests
 - Verify testing results
 - Collect documentation and issue final CX report
 - Begin to orchestrate training

The Commissioning Process

```

    graph LR
      A[Predesign] --> B[Design]
      B --> C[Construction]
      C --> D[Occupancy/Operation]
      style C fill:#90EE90
  
```

- CxA Review of submittals
 - Focus on equipment and systems to be commissioned, compliance with specifications and commissioning facilitation and project management sign offs

The Commissioning Process

```

    graph LR
      A[Predesign] --> B[Design]
      B --> C[Construction]
      C --> D[Occupancy/Operation]
      style C fill:#90EE90
  
```

- CX progress reports
 - Update issue log
 - Do it in a regularly scheduled fashion
 - Tie it to certain meetings

The Commissioning Process

```

    graph LR
      A[Predesign] --> B[Design]
      B --> C[Construction]
      C --> D[Occupancy/Operation]
      style C fill:#90EE90
  
```

- Pre-functional checklists (aka "Construction Checklists")
 - Static inspection prior to initial operation by contractor
 - CA to witness or verify
 - Major equipment: 50 – 100% (ex. Boilers, AHUs, Switchgear)
 - Minor equipment: 10-50% (ex. Lighting controls)
 - Terminal equipment: 2-10% (ex. Fan coil units)

The Commissioning Process

```

    graph LR
      A[Predesign] --> B[Design]
      B --> C[Construction]
      C --> D[Occupancy/Operation]
      style C fill:#90EE90
  
```

- Finalize Functional Tests
 - Dynamic systems testing under operating conditions
 - Establish details for testing (as outlined in bid document specifications)
 - Provide overview of test procedures to CX team
 - Develop test procedures in coordination with and with input from applicable contractors

The Commissioning Process

```

    graph LR
      A[Predesign] --> B[Design]
      B --> C[Construction]
      C --> D[Occupancy/Operation]
      style C fill:#90EE90
  
```

- Schedule and Execute Functional Tests
 - Only after Pre-functional checklists have been completed
 - Witness and document testing as conducted by applicable contractors
 - Deficiencies documented and reported to owner
 - Deficiencies corrected

The Commissioning Process

```

    graph LR
      A[Predesign] --> B[Design]
      B --> C[Construction]
      C --> D[Occupancy/Operation]
      style C fill:#90EE90
  
```

- O&M manuals and warranties
 - Review submissions from contractors
 - Request EARLY in the process
 - Compile commissioning record
 - Final CX plan
 - Final CX report (system manual)
 - Issue logs and progress reports
 - Equipment documentation (checklists, test, etc.)
 - Training and orientation
 - Coordinate and document training scope, process, and intended audience

The Commissioning Process

```

    graph LR
      A[Predesign] --> B[Design]
      B --> C[Construction]
      C --> D[Occupancy/Operation]
      style C fill:#90EE90
  
```

- Final Cx Report (aka Systems Manual)
 - Executive Summary
 - List of participants and roles
 - Overview of Cx scope and methodology
 - Status of all equipment and systems
 - Design intent compliance
 - Functional performance
 - Testing
 - Future recommendations
 - Continuous Cx action plan
- Appendix
 - Meeting minutes
 - Deficiency reports
 - Progress reports
 - Issue logs
 - Training logs

The Commissioning Process

```

    graph LR
      A[Predesign] --> B[Design]
      B --> C[Construction]
      C --> D[Occupancy/Operation]
      style C fill:#90EE90
  
```

- Role of the A/E
 - Punchlists, RFIs, payment/change order review
 - Participate in resolution of deficiencies
 - Participate in O&M documentation and training
- Role of the Owner (or CM/GC)
 - Arrange for operating personnel to be available for system testing and training
 - Force execution of Functional Test procedures
 - Force resolution of non compliant issues

The Commissioning Process

```

    graph LR
      A[Predesign] --> B[Design]
      B --> C[Construction]
      C --> D[Occupancy/Operation]
      style C fill:#90EE90
  
```

- Role of the GC
 - Integrates Cx into overall construction schedule
 - Coordinate Cx participation of sub contractors
 - Review Cx submittals from sub contractors
- Role of the subcontractors (MC, CC, EC, etc.)
 - Complete Pre-functional Checklists
 - Participate in development of Functional Tests
 - Perform Functional Tests in coordination with Cx team

The Commissioning Process

```

    graph LR
      A[Predesign] --> B[Design]
      B --> C[Construction]
      C --> D[Occupancy/Operation]
      style D fill:#90EE90
  
```

- Begins at Substantial Completion
- Commissioning Activities performed during this phase often continue through the warranty phase.
- Any work being completed now should be verified against the OPR
- What are the objectives of this phase?

The Commissioning Process

```

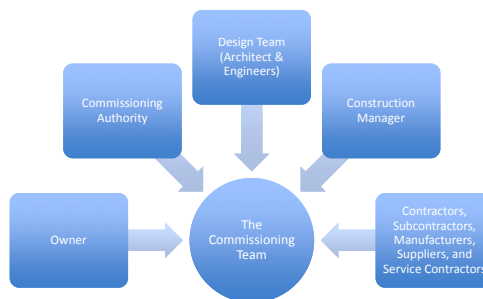
    graph LR
      A[Predesign] --> B[Design]
      B --> C[Construction]
      C --> D[Occupancy/Operation]
      style D fill:#90EE90
  
```

- Commissioning Team Members during the Occupancy/Operations Phase
 - Owner's Representative
 - Commissioning Authority
 - Design Professionals
 - Contractors
 - Construction/Program/Project Managers
- What are the Roles of the Commissioning Team during this Phase?

LECTURE 3

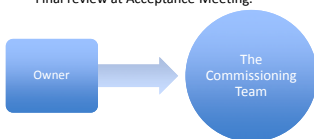
The Commissioning Team

The Commissioning Team



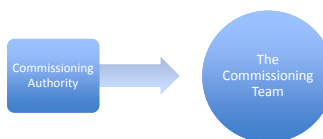
The Owner's Responsibilities

- Develop, review, and approve any changes to the Owner's Project Requirements (OPR).
- Review all work submitted by the Commissioning Authority.
- Assign Owner's Representative to participate in Cx process:
 - Design Phase Coordination Meetings
 - Construction Phase Coordination Meetings
 - Commissioning Meetings
 - Owner Training Sessions
 - Witness Functional Testing and/or Verification Demonstration
 - Final review at Acceptance Meeting.



The Commissioning Authority's Responsibilities

- Organize, direct, and lead the Commissioning Team
- Facilitate and document the Owner's Project Requirements.
- Create the project commissioning specifications or review specifications for compliance with the Commissioning process and plan
- Integrate the Commissioning Process activities into the project schedule.
- Prepare a Commissioning Plan that meets the OPR, then continually update it.
- Review and Comment on the ability of the design documents to achieve the OPR
- Conduct equipment submittal reviews to ensure compliance with OPR and design.



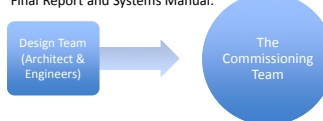
The Commissioning Authority's Responsibilities

- Witness selected systems factory testing, equipment startup activities, contractor testing, and/or test and balance activities for compliance with documents. Review written reports for accuracy and compliance.
- Conduct static installation inspections on equipment and systems; Provide Prefunctional Checklists to team and Review completion of Prefunctional Checklists by contractors.
- Direct, witness, and document equipment systems Functional Testing.
- Document issues (design, construction, turnover) in Commissioning Issues Log; Assist in resolution of issues thru clear documentation, ongoing communication with commissioning team, and verify closed issues thru review, static inspections and/or retesting. The responsible party is responsible for resolving issues per project contract.
- Review contractor provided O&M Training program and ensure effective execution
- Review the Systems manual provided by the contractor
- Review drawings for compliance with installed systems
- Verify that all documentation has been updated throughout the construction phase
- Recommend acceptance of systems upon successful completion of functional testing, closure of issues, and delivery of all required documentation and training.



Design Team Responsibilities

- Review the Owners Project Requirements and ensure that the design achieves the owner's intent; Respond to OPR by creating the Basis of Design (BoD) document.
- Attend coordination meetings, pre-Bid, pre-construction, and Commissioning Meetings throughout the project.
- Review, respond, and incorporate (as appropriate) the Commissioning Authority's comments from design reviews, submittal reviews, and issues log.
- Present the Basis of Design at the initial operation and maintenance personnel and occupant training sessions.
- Review and comment on the Commissioning Authority's progress reports and documentation, including Prefunctional Checklists, Functional Test Procedures, Final Report and Systems Manual.



Construction Managers Responsibilities

- Conduct all work in accordance with Contract Documents
- Include costs for Commissioning Process activities in the contract price
- Provide acceptable representation with the means and authority to prepare, schedule, and coordinate implementation of the Commissioning Process
 - Attend Commissioning Meetings and ensure all trades attend Commissioning Meetings
 - Ensure contractor staffing and execution of the Prefunctional Checklists and Functional Testing.
 - Direct the resolution of Commissioning Issues; Ensure trades respond and resolve issues identified.
- Include Commissioning Process milestones in the project schedule
- Collect and Provide required documentation for verification by the CxA, including:
 - Operations and Maintenance Training Plan and Training Agenda, Manuals, and Operating Instructions for Systems.
 - Systems Startup and Contractor Test Reports

```

            graph LR
            CM[Construction Manager] --> CXT((The Commissioning Team))
            
```

Contractor Responsibilities

- Conduct all work in accordance with Contract Documents and Commissioning Plan
- Include costs for Commissioning Process activities in the contract price
- Attend Commissioning Meetings
- Include Commissioning Process milestones in the Project Schedule; Provide accurate dates for CxA witnessing of factory testing, equipment startup, contractor testing, TAB, and controls checkout, and commissioning functional testing
- Provide preliminary and final equipment and systems contractor test reports to the Commissioning Authority

```

            graph LR
            C[Contractors, Subcontractors, Manufacturers, Suppliers, and Service Contractors] --> CXT((The Commissioning Team))
            
```

Contractor Responsibilities

- Execute Prefunctional Checklists, Functional Testing, and retesting under the direction of the Commissioning Authority
 - Accurately complete all provided Prefunctional Checklists prior to Functional Testing.
 - Conduct Commissioning Functional Testing under direction of the CxA; Demonstrate the performance of equipment, assemblies and systems to the Commissioning Authority
- Provide timely responses to Commissioning Issues identified; Resolve Commissioning Issues as required; Provide verification of resolution of issues to satisfaction of CxA
- Maintain the Record Drawings and submit as detailed in the Contract Documents
- Implement the Training Program as detailed in the Contract Documents
- Provide all information required for the operation and maintenance of the systems, including recommended schedule of maintenance requirements and frequency.
- Provide Operations and Maintenance Manuals per project requirements
- Provide all warranty details and the requirements to maintain the warranty

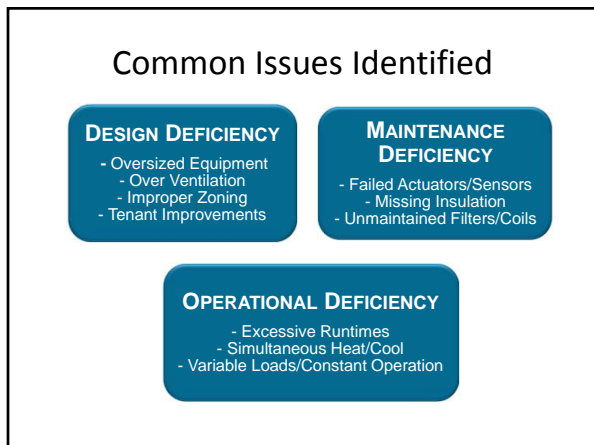
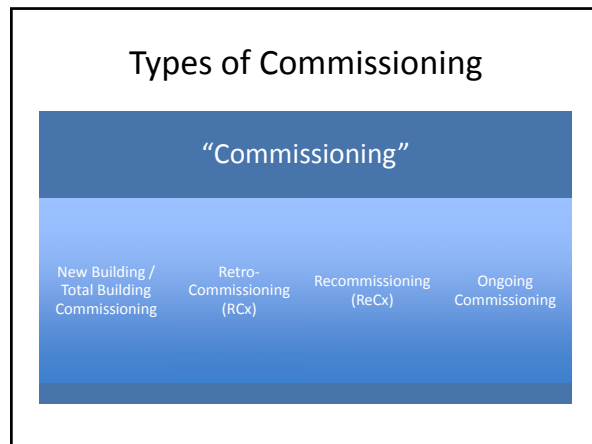
The Commissioning Team


```

            graph TD
            CA[Commissioning Authority] --> CXT((The Commissioning Team))
            DT[Design Team Architect & Engineers] --> CXT
            CM[Construction Manager] --> CXT
            O[Owner] --> CXT
            C[Contractors, Subcontractors, Manufacturers, Suppliers, and Service Contractors] --> CXT
            
```

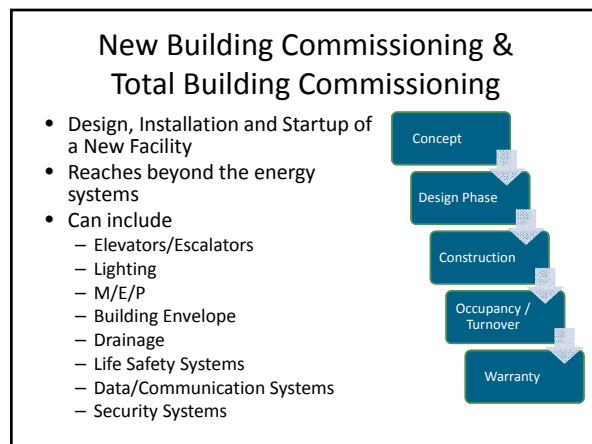
LECTURE 4

Commissioning Types, Buildings, and Systems



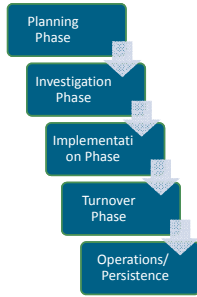
- ### When to Commission a Facility
- **New Construction Commissioning**
 - Owner invested in receiving a fully functional facility
 - Educational Facilities, Residential, Office, Government, etc.
 - Complex Building, Mission Critical, or Energy-Intensive
 - Laboratories, Healthcare Facilities, etc.
 - Achieve LEED Requirements
 - **RetroCommissioning of Existing Buildings**
 - Facility was never commissioned before; 15 years old or younger
 - Recent changes in tenant spaces
 - Excessive thermal comfort complaints
 - Multiple building portfolio
 - HVAC Equipment is in good condition but energy benchmarking shows opportunity.
 - **ReCommissioning of Existing Buildings**
 - Facility was Cx'd previously, but many changes have been made.
 - Energy bills are not what they used to be.
 - O&M staff has had turnover.
- 

- ### Systems to be Commissioned
- | | |
|--|---|
| <ul style="list-style-type: none"> • Mechanical/ HVAC <ul style="list-style-type: none"> - Boilers, Chillers and Pumping - Air Distribution • Electrical <ul style="list-style-type: none"> - Feeders, distribution, grounding - Emergency power system - Lighting and Controls - Power Conditioning - Monitoring - Lightning Protection • Building Envelope & Acoustics • Plumbing Systems <ul style="list-style-type: none"> - Domestic Hot Water - Water Conditioning Systems - Storm and Sump Pumps - Wastewater - Condensate collection - Medical Gas/Vacuum | <ul style="list-style-type: none"> • Building Automation System <ul style="list-style-type: none"> - Sensors, Transmitters, Actuators, Controllers - Network and Interface - Equipment Alarm points, graphic user interface, and trending functionality. - Interfaces between BAS and fire detection/alarm, security, and emergency power generators. • Life Safety Systems <ul style="list-style-type: none"> - Fire Protection (Wet/Dry Sprinkler) - Fire Detection and Alarm - Strobes/Horns and Elevator Recall - Smoke Management and Control - Fire/Jockey Pump • Communication, Data, and Security |
|--|---|



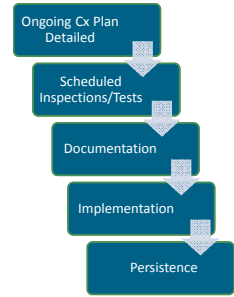
Retro-Commissioning & ReCommissioning

- Emphasizes Low Cost / No Cost O&M Improvements
- More thorough On Site Assessments
- Facility Improvement Measures
- Typically Fast and Inexpensive to Implement



Ongoing Commissioning

- Educated Maintenance Staff
- Continuous formal review of sensors, setpoints, and controls sequences.
- Additional Cx upon facility expansion, space changes, or addition of equipment



LECTURE 5

Commissioning Costs and Benefits

Cost and Value of Commissioning

NEW CONSTRUCTION	EXISTING BUILDING
Cost: \$0.85 - \$2.00 / GSF	Cost: \$0.10 - \$0.60 / GSF
Median Cost: \$1.25 / GSF	Median Cost: \$0.16 /GSF
Value of Energy Savings: \$0.02-\$0.19/GSF	Value of Energy Savings: \$0.11-\$0.72/GSF
Value of Non-Energy Savings: \$0.23- \$6.96/GSF	Value of Non-Energy Savings: \$0.10- \$0.45/GSF
Typical Payback: 4-6 Years	Typical Payback: 6-12 Months
	Typical Energy Savings: 15%

- Most Successful: Complex, Energy-Intensive Buildings
- Energy Savings increase with Commissioning
- Cost-effective outcomes are more difficult to achieve in small buildings.

- ### Benefits to the Construction Team
- NEW CONSTRUCTION
- Improved coordination between design, construction, and occupancy phases:
 - Improved planning and coordination through the implementation of the commissioning plan
 - Defined metrics for success
 - Resolves issues
 - Decision making
 - Reduced number of Change Orders
 - Fewer system deficiencies at building turnover
 - Reduced number of deficiencies at substantial completion, reduced warranty phase calls, and reduced issues due to seasonal performance.
 - Reduced number of callbacks
 - Improved coordination between different trades and reduced likelihood of site interference drawings required of contractors throughout the project.
 - Reduced number of calls for operational guidance due to participation in training programs for operations and maintenance personnel.

- ### Benefits to the Design Professional
- NEW CONSTRUCTION
- Facility will achieve the goals of Owner’s Project Requirements
 - Reduced risk exposure
 - Improved knowledge base for use in future designs and installation
 - Benefits of other participants’ input, leading to the most cost-effective design and operation
 - Reduced number of interference drawings during construction due to improved communication and coordination throughout the project

- ### Benefits to the Owner
- NEW CONSTRUCTION
- Assurance that facility is designed and constructed to specific parameters defined in OPR.
 - Assurance that project requirements and performance is achieved.

- ### Benefits to the Owner
- | NEW CONSTRUCTION | EXISTING BUILDING |
|---|-------------------|
| <ul style="list-style-type: none"> • Improved Indoor Environmental Quality (IEQ)
The quality of indoor environment can affect the health, comfort and productivity of it’s occupants <ul style="list-style-type: none"> – Causes of Poor Indoor Air Quality: <ul style="list-style-type: none"> ▪ Moisture and mold in the building envelope ▪ Inadequate outside air ventilation or Poor air circulation ▪ Inappropriate control of ventilation air ▪ Poor craftsmanship in the air distribution system – Discomfort is Costly (Productivity, Retention, Liability) • Higher quality work environment and Indoor Environmental Quality (IEQ) can lead to: <ul style="list-style-type: none"> – Improved workplace performance reduced complaints, and reduced incidence of absenteeism – Reduced risk from threats, and prevention of business losses | |

Benefits to the Owner

NEW CONSTRUCTION

EXISTING BUILDING

- Improved Efficiencies and Operations & Maintenance System Operational Techniques:
 - Improved operator knowledge to optimize the facility due to the early inclusion of maintenance and training requirements.
 - Staff receives appropriate and thorough training reduces downtime due to better diagnosis of failures.
 - Project As-Build documentation and O&M Manuals are complete; Systems Manual provides an easy reference document for system and assembly.
 - Increased knowledge of performance criteria of facility and energy expectations.
 - Improved ability to provide accurate information to occupants on facility operation and maintenance.

Overall Benefits of Commissioning

Commissioning assists in project that:

- Provides a safe and healthful facility;
- Provides a facility that is designed and constructed to owners needs and requirements;
- Optimizes energy use;
- Reduces operating costs;
- Ensures adequate O&M staff orientation and training;
- Improves installed building systems documentation.

DOE

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 - Cx Lead Cont...
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 - Building Owner's Represent
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Beginning of Lesson 1

UNIVERSITY OF Nebraska Lincoln

Reading Assignments:

Section 3 of California Commissioning Guide, New Buildings

"Request for Commissioning Services" (Sample Doc)

Lesson 1

Developing the Commissioning Team

U.S. DEPARTMENT OF ENERGY mGROUP design+green

Glossary Read 103 of 566

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Introduction

Introduction

- Who is on the commissioning team?
- What are the roles of the each team member?
- Who Leads the commissioning team?

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Cx Team Members

Commissioning Team Members

- Commissioning Lead
 - Design Professionals
 - Systems Specialists
- Building Owner/Owner's Representative
- Building Manager and Staff
- Design Professionals
- Contractors and Manufacturer's Representatives

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Cx Lead

Role of Commissioning Lead

- Organize and lead the commissioning team
- Ensure that the owner's expectations are met through:
 - The Owner's Project Requirements
 - Basis of Design, and,
 - Design Narrative
- Review Design Submittals
- Assist in documenting the commissioning requirements in the specifications

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Cx Lead Cont...

Role of the Commissioning Lead Cont...

- Prepare and update the Commissioning Plan
- Develop and Maintain an Issues Log
- Observe and document functional testing
- Verify systems manual is complete
- Develop staff training
- Complete final commissioning report
- Insure deferred testing is completed

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 - Selecting Cx Lead Cont...
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Cx Lead Cont...

Role of the Commissioning Lead Cont...

- Design Professionals
 - Help commissioning lead develop the Owner's Project Requirements
 - Help resolve issues that arise during construction
- Systems Specialists
 - Perform Design Reviews
 - Perform Pre-functional and Functional Testing
 - Help with training efforts

Glossary Read 108 of 566

DOE N

Index Presented by Unison

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Module 2

Preparation and Objectives
Course Topics
Time Allotment

Lesson 2.1

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- Building Owner's Represent
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- Selecting Cx Lead Cont...
- Sample Request for Cx Ser
- Sections

Building Owner's Representative

Role of Building Owner/Owner's Representative

- Clearly communicate the project expectations
- Hire commissioning lead
- Assign staff to represent the owner's interests during the commissioning process
- Work closely with commissioning lead to determine a detailed commissioning scope
- Review Reports submitted by the commissioning lead

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Building Owner's Representative Cont...

Role of Building Owner/Owner's Representative Cont...

- Approve startup and functional test completion
- Begin including future building staff in the process
- Consider the recommendations of the commissioning lead when directing the construction team or accepting building or systems

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Building Staff

Role of Building Staff

- Review designs for maintainability
- Participate in periodic site walk-throughs
- Participate in commissioning process meetings
- Observe functional testing
- Participate in training sessions

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Contractors and Manufacturer's Representative

Role of Contractors and Manufacturer's Representative

- Attend Pre-bid and pre-construction meetings
- Integrate commissioning milestones into the construction schedule
- Supply the commissioning lead with all requested drawings and respond to requests for information and change orders
- Approve and carry out functional testing
- Work with the commissioning to remedy deficiencies
- Provide documentation for the systems manual
- Develop and conduct training for building staff

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Selecting Cx Lead

Selecting a Commissioning Lead

- Qualifications
 - Technical Knowledge
 - Relevant Experience
 - Communication Skills
 - Organizational Skills
 - References and sample works
 - Objectivity

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Selecting Cx Lead Cont...

Selecting a Commissioning Lead

- Commissioning Lead Arrangements
 - Owner's Staff
 - Design Engineer and Architect
 - Contractor
 - Independent third-party

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Selecting a Commissioning Lead

- The Selection Process
 - Selection Proposal
 - Selection Qualification

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Sample Request for Commissioning Services

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Sections

Sections

- Background
- Objectives
- Scope of Work
 - Pre-Design Phase
 - Design Phase
 - Bid Phase
 - Construction Phase
 - Warranty Period

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Sections Cont...

Sections

- Systems to be Commissioned
- Desired Qualifications
- Pre-Proposal Meeting
- Proposal
- Selection Process
- Change in personnel
- Addenda
 - Scope Review Matrix
 - Firm Experience Information Sheet
 - Firm Commissioning Experience Sheet
 - Commissioning Budget

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 - Background
 - Objectives

Background

Background

- Basic building information
 - Size, type, location
- Constraints
 - Simple Budget and Schedule
- Current Phase

Background

The Owner is seeking the services of a qualified commissioning provider firm for a new construction project. The project currently is a _____ phase of _____ story Class _____ building in (city & state) _____ with a project budget of \$ _____ million. The facility is expected to be completed by _____ % in (month, year) _____ office space, _____ % medical laboratory, etc.

WHERE: DELIVERABLES AND SPACES TO WHICH SPECIFIC PROJECT PROVIDER AS MUCH INFORMATION AS POSSIBLE

The current phase of the project is _____ (PRE-DESIGN, SCHEMATIC DESIGN, DESIGN DEVELOPMENT, CONSTRUCTION DOCUMENTS). The construction documents are planned to be completed by _____ Construction is anticipated to begin in _____ and final occupancy by _____ Project documents available for review _____

WHERE: PROVIDE THE PROPOSER WITH A COPY OF THE PROGRAMMING REPORT AND ANY DESIGN/LOADS COMPLETED TO DATE

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 - Objectives
 - Scope of Work

Objectives

Objectives

- Goals for facility
 - Functionality
 - Maintainability

Objectives

NOTE: THE USER SHOULD DEVELOP HIS OWN GOALS AND OBJECTIVES

The objective of commissioning is to provide the owner with confidence that the facility will be functional and perform as expected throughout its life cycle. The goal is to ensure that the commissioning process is visible and transparent to the owner, contractors, and all stakeholders. The objective of commissioning is to provide the owner with confidence that the facility will be functional and perform as expected throughout its life cycle. The goal is to ensure that the commissioning process is visible and transparent to the owner, contractors, and all stakeholders.

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Scope of Work

Scope of Work

- Pre-design Phase
 - Determine Tasks to be completed during Pre-design Phase
- Must Include
 - Owner's Project Requirements (OPR)
 - Basis of Design (BoD)

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Scope of Work Cont...

Scope of Work

Design/Bid Phase

- Continue to develop the commissioning plan
 - Design Phase (Revise)
 - Construction Phase (Draft)

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Scope of Work Cont...

Scope of Work

Construction Phase

- Integrate Commissioning Activities Into project schedule
- Revise Commissioning Plan
 - Construction Phase Commissioning Plan (Revise)
 - Warranty Phase Commissioning Plan (Draft)

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Scope of Work Cont...

Scope of Work

Construction Phase

- Review Documentation for continued compliance with the commissioning plan
 - RFI's
 - Change Orders
- Develop Contractor Checklists
- Perform Pre-functional task

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Scope of Work Cont...

Scope of Work

Construction Phase

- Develop Issue Log
- Compile Systems Manual
 - OPR
 - BoD
 - Performance Metrics
 - Schematic Drawings
 - Control drawings and sequences
 - Equipment Set points
 - Operations and Maintenance Schedule

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Scope of Work Cont...

Scope of Work

Warranty Period

- Perform or supervise opposite season/deferred testing
- Conduct 12 month warranty review with building staff
 - Issues
 - Updates
 - Concerns

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Systems to be Commissioned

- Delete and add systems per building design
- List should be kept general when developed during pre-design stage (See list to the left)
- Add details once specifications and designs near-complete or completed

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Qualification of Cx Agent

Desired Qualification of Commissioning Agent

- Minimum number of projects as a commissioning agent
- Experience with operation speciality systems
- Required Field Experience
- Understanding of operation and maintenance procedures

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Pre-proposal meeting

Pre-proposal meeting

- Used to clarify project issues
- Informational
- Not typically required

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Proposal

Proposal

- Establish desirable limits
 - Page length, size, format
- Ensure proposer is in authority to commit the firm
 - Insurance forms
- State specific content
 - Organizational Structure
 - Staff members involved with each phase
 - Resumes
 - Relevant work experience
- Identify approach to project (the proposed solution)
- State durations, costs, and contingencies

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Selection Process

Selection Process

- Have a score sheet set and supply to proposers
- Base selection on predetermined score sheet with emphasis on:
 - Proposed approach
 - Past experience
 - Expertise
 - Fee

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Change in Personnel

Change in Personnel

- All personnel changes should be reviewed and approved by the owner prior to making a change.

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Appendices

Appendices

- Pages 10-13 of reading have sample documents to be attached as appendices to the Request for Commissioning Service packet.

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End of Lesson 1

Developing the Commissioning Team

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- OPR Workshop Steps
- Develop Questions
- Which Question is Best?
- Which Question is Best?
- Which Question is Best?
- Which Question is Best?
- Organize the Workshop
- Who to Invite?

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Reading Assignments:

Developing Owner's Project Requirements During Pre-Design-Chad Dorgan

The Owner's Project Requirements and where it fits in the Design Process

Sample OPR

Lesson 2

Developing Owner's Project Requirements During Pre-Design

U.S. DEPARTMENT OF ENERGY mGROUP design.green

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- Who to Invite?

OPR Development Methods

- Workshops
- Interviews
- Surveys

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- Which Question is Best?
- Which Question is Best?
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- Who to Invite?

OPR Workshop Steps

- Develop Questions
- Organize the Workshop
- Hold the Workshop
- Analyze the results
- Present the results
- Update the procedures

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- Which Question is Best?
- Which Question is Best?
- Organize the Workshop
- Who to Invite?

Develop Questions

Step 1: Develop Questions

- Questions should be Broad in Nature:
 - Elicit Discussion
 - Establish Multiple view points
 - Does not lead the workshop
- Includes Owner's and Occupant's Concerns
- Establish time limit for answering each questions
 - Typically 20 to 30 minutes

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- Which Question is Best?
- Which Question is Best?
- Which Question is Best?
- Organize the Workshop
- Who to Invite?

Which Question is Best?

- What do you do in the building?
- What are the functional requirements of this building?
- What equipment is in the building?

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- Who to Invite?

Which Question is Best?

- What temperature are you comfortable at?
- List conditions important to your comfort in an ideal building.
- Do you dress differently in winter vs. summer?

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 - Design Review Cont..
 - Coordination Review

Beginning of Lesson 3

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Reading Assignments:
BOD Development Assistant Document for
Architectural/Engineer Design Process-Building Energy
Sciences, LLC
BoD for Eastern Maine Medical Center
Sample Specification: The Green School

Lesson 3

**The Basis of Design (BoD) /
Commissioning Specification**

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 - Cx Plan Cont..
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 - Design Reviews Cont..
 - Design Review Cont..
 - Design Review Cont..
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Basis of Design (BOD)

- Explains the what and why portions of the design
- Prepared by AE firm
- Defines how the OPR will be achieved
- Reviewed by the CxA

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 - Design Review Cont..
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Basis of Design Cont..

Basis of Design (BOD)

- Developed during the design phase
- Continuously updated as the project and design evolves
- Supplemented by project design guides and cut sheets

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Basis of Design Cont..

Basis of Design (BOD)

- Translates OPR into a working design
- Sections include:
 - Design assumptions
 - Selection of system components
 - Codes and standards used
 - Owner directives

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Cx Specification

Commissioning Specification

- Cx requirements specific to the project
- Outlines Cx requirements for all systems identified
- Included as part of individual specification sections
 - Separate Sections
 - Integrated sections

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Cx Specification Cont..

Commissioning Specification

- Separate Commissioning Section
 - Requires least coordination between AE/CxA
 - Single spec location
 - Calls attention to commissioning
- Integrated sections
 - Integrated within individual sections
 - Requires more coordination
 - Something could get missed resulting in change order

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Process Responsibilities

Includes Process Responsibilities

- Defines individual roles and responsibilities
- Equipment checklist completion
- Meeting participation
- Systems Manuals
- Owner Training
- Timing and coordination of activities

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Sample Documents

Basis of Design (BOD)

- Gives a better idea of what is expected
- Eliminates guessing when gathering bids
 - Commissioning Plan
 - Training Plan
 - OPR
 - Equipment Checklists
 - Sample Functional Tests

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The Basis of Design (BoD) / Commissioning Specification

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Reading Assignments:

- [The Commissioning Process – California Commissioning Collaborative](#)
- [Appendix 4 – How to Develop a Commissioning Plan](#)
- ASHRAE Guideline 0
- ASHRAE Guideline 1

Lesson 4

The Commissioning Plan and Design Reviews

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Cx Plan

Commissioning Plan

- Outline of Process
- Defines Roles
- Sets Expectations
- Provides Submittal Requirements

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Cx Plan Cont...

Commissioning Plan

- Covers what is planned at design phase and what is designed during construction phase (can be separate versions)
- Document issues and deviations from OPR
- Develop functional test requirements
- Defines training program requirements

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Cx Plan Cont...

Commissioning Plan

- General guidance for the commissioning team
- Follows design and construction phase tasks
- As project proceeds commissioning plan is updated
- Eventually evolves into the final commissioning report
- Examples provided in ASHRAE Guideline 0

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Design Reviews

- Performed at specific design phase submissions -50 %, 75%, and 100% Construction Documents
- Focused review on achieving OPR
- Is it being met?
- Does BOD make sense according to design?
- Examples provided in ASHRAE Guideline 0

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Design Reviews Cont...

Design Reviews

- Incomplete reviews are an issue.
- Use the OPR as Criteria
- Use statistical sampling approach (10%-15%)
- Use specific checklists

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Reading Assignments:

- ASHRAE Guideline 0
- ASHRAE Guideline 1
- Writing a Functional Test
- Tests-Air Handlers
- Tests-Chillers
- Sample Test for Fire and Smoke Dampers

Lesson 5

Construction Phase Commissioning

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Pre-Construction Workshops

- CxA to hold pre-construction workshops
 - Educate contractors in Cx process
 - Share OPR and BOD
 - Set expectations
 - Define expected benefits
 - Discuss contract documents

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Pre-Construction Activities

- Submittals review
- Does it meet the OPR
- Review of control submittal is crucial
- Are all critical components provided.
- Schedule review – adding of commissioning activities

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CxA Responsibilities During Construction

- Advocate for the Owner
- Teamwork and Partnering
- Coordinating Team Meetings
- Field Walkthroughs
- Tracking Cx Activities
 - Issues Log
 - Meeting Minutes
- Cx Scheduling
- Verify, Manage and Participate in Commissioning Process Tests, TAB, and EMS Testing as Project Requires
- Review all Cx Documentation

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Equipment Checklists

Development of Equipment Checklists

- Specific to each project and piece of equipment
- Prepares the equipment for startup and testing
- Approved by owner and maintenance staff
- Signed off by installing contractor and CxA at completion
- Good examples within ASHRAE Guideline 0.

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Functional Performance Testing

- Performance Testing
 - Operation of the Equipment and all Components and Controls
 - Spot checking of TAB readings
 - Point to point checks for BAS
- Integrated Systems Tests (IST)
 - Verify Overall Operation of Systems Integration
 - Verify Alarms
 - Verify Emergency Operation
 - Bring Back on Main Power
 - Used on healthcare, lab, and data center environments

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Construction Phase Commissioning

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Reading Assignments:

ASHRAE Guideline 0

ASHRAE Guideline 1

Lesson 6

Owner Training and Systems Manual

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Owner Training and Systems Manual

- Requirements in all Phases
 - Pre-Design
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Systems Manual

- Typically disorganized paper or static electronic format that is component based rather than systems based
- Should be editable, with some static parts
- Can be either paper or electronic format
- Should have a required layout that provides:
 - Systems and components
 - Parts list with warranties
 - TAB reports
 - Approved Submittals

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Training Items

- Have written expectations of training
- Make sure that all training is tailored to O&M needs
- Get approval of plan/material prior to training
- Record training
- Evaluate training and verify comprehension through performance tests

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During Programming

- Conduct workshop for OPR to determine training needs and requirements for the O&M systems manual
- Discuss System Complexity
- Review Lessons Learned

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Design - Systems Manual

- DD Specifications
 - Required contents
 - Draft copies 30-60 days after submittal approval
 - Final copies 30 days prior to training
 - Electronic formats or media acceptable
- Review CDs for discrepancies

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Design - Training

During Design - Training

- DD Specifications
 - Systems requiring training and the scope required
 - Type and location of training
 - Training duration
- Review CDs for discrepancies

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Construction - Systems Manual

During Construction - Systems Manual

- Review systems manual draft submittal
- Review systems manual final submittal
- Help contractors to understand electronic manual

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Construction - Training

During Construction - Training

- Final attendee list
- Training matrix
- Training schedule

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Turnover

During Turnover

- Contractor provides final manual copies
- Final training program
- Evaluate training
- Improve based on feedback

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Operation

During Operation

- Promote distribution and safe keeping of the manuals
- Provide additional training if needed
- Evaluate the usage and updating of the manuals

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Owner Training and Systems Manual

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 - Liquid Moisture
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 - Location of Air Barrier

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Reading Assignments:
ASHRAE Guideline 0
ASHRAE Guideline 1

Lesson 7

Final Reports and Warranty Walkthrough

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Final Reports

- Cx plan
- Completed forms
- Issues logs
- Documented benefits
- Evaluations and Recommendations
- Systems manual
- Training records and evaluation

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Warranty Walkthrough

- Define In specification
- Usually at 10 months
- Driven by Owner and CxA
- Identify issues as warranty reimbursable items

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Systems Manual

- Periodically during first year
 - Verify operation
 - Continued training
 - Re-commissioning
 - Documentation
 - Warranty maintenance

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Final Reports and Warranty Walkthrough

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Reading Assignments:
National Institute of Building Sciences (NIBS)
Guideline 3-2006

Lesson 8

Building Envelope Commissioning

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Building Envelope Cx

Building Envelope Commissioning

- Construction
- Moisture control
- Air flow
- Visual Inspection
- Qualitative and quantitative testing

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Envelope Systems

Construction of Envelope Systems

- Attend site and mockups testing
- Check against energy code
- Report testing and inspections
- Documents for maintenance
- Training

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Moisture Control

Moisture Control

- Influences
- Envelope assembly
- Exterior weather
- Interior conditions

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Weather

Moisture Control - Weather

- Wind driven rain
- Water vapor
- Temperature
- Solar radiation
- Cloud cover

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Wetting Mechanisms

Moisture Control - Wetting Mechanisms

- Precipitation
- Ground water
- Water vapor
 - Air pressure differences
 - Convection
- Diffusion through building materials

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Liquid Moisture

Moisture Control – Managing Liquid Moisture

- Roofs 3 Ds (deflection, draining, and drying)
- Below grade
- Above grade walls

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Air Barrier System

Location of Air Barrier

- Anywhere in envelope system
- If on warm side can be a combination air and vapor barrier
- If on cold side have permeance at least 10 times the permeance of vapor retarder

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Location of Air Barrier

Location of Air Barrier

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- If on cold side have permeance at least 10 times the permeance of vapor retarder

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Testing and Verification

Testing and Verification

- All aspects of envelope (not just openings)
 - Inspection
 - Visual
 - Testing
 - Quantitative
 - Qualitative

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Reading Assignments: NECA 98 - 2009

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Electrical Systems Cx

Electrical Systems Commissioning

- Varying levels of electrical commissioning depending on:
 - Type of facility
 - Type of electrical system
 - Jurisdiction
 - Owner's intent
 - Budget
 - VE

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Levels of Electrical Cx

Levels of Electrical Commissioning

- Low level commissioning
 - Warehouse
 - Multi-tenant commercial
 - Retail
 - Light Industrial
- Higher level commissioning
 - Low rise and high rise commercial property
 - Light industrial and manufacturing facilities
 - Schools
 - Facilities with security needs
- Highest level commissioning
 - Hospitals and healthcare facilities
 - Banking and data centers
 - Telecom sites
 - Hazardous material facilities
 - High security installations
 - Many government installations

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Low Level Cx

Low Level Commissioning

- Performed on all facilities
 - Main electrical switch gear and ground fault trip system
 - Test building grounding system, earth ground test
 - Transformer and system grounds
 - Life safety systems
 - Fire alarm system
 - Infrared survey of electrical system under load

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Higher Level Cx

Higher Level Commissioning

- Test lighting and ventilation in parking garages
- Building power management system
- Music, intercom and paging systems
- Security and camera systems
- Specialty lighting systems
- Dimming systems, daylight harvest sensors, occupancy sensors, etc.

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Highest Level Cx

Highest Level Commissioning

Critical Facilities and Data Centers:

- Set breakers trip time & current per the coordination study
- Injection test all circuit breakers
- Test Generators, paralleling switchgear and Controls.
- UPS Systems, perform minimum 4 hr load bank tests, operate in all modes, perform infrared thermal scan of UPS internal component.
- Perform UPS timed battery rundown test at full load. IR scan batteries and connections during discharge.
- Perform infrared thermal scan of all UPS input & output, normal & bypass feeders and breakers with designed loads applied with load bank.

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Highest Level Cx

Highest Level Commissioning

Data Centers:

- Perform load testing of utility, generator and UPS system feeders, panels, breakers and PDU's or RPP's by connecting load banks on the data room floor.
- Install load banks inside data center to produce head load on CRAC units and entire cooling system. Switch CRAC's on and off to check redundancies and load each system.
- Perform infrared scan of all electrical equipment, feeders, breakers and panels supporting the loads.
- Most systems are tested three times.
 - Component acceptance test
 - System functional tests
 - Integrated System Test

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Design Review

Design Review

- Compare owners design intent and BOD with drawings and specs
- Compatibility of "as equal" submittals or VE items
- One line drawings and submittals
- Redundancy to meet project specs
- Review preliminary outline of commissioning plan with architect and M&E firm
- Determine who is responsible for the coordination study
- Verify short circuit analysis will be complete in time for electrical bid and that the coordination study, protective device settings and arc fault hazard study will be complete in time for testing.
- Assist architect and M&E firm incorporating commissioning specs into bid documents.

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Preparation and Objectives

Lighting Systems

Design Review – Lighting Systems

- Keep lighting controls zones as small as possible
- Avoid having too much sunlight
- Use correct sensors with optimal placement
- Review shop drawings for compliance with design
- Review owner and occupant training plans

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Testing Deliverables

Testing Deliverables

- Test forms
- Calibration certificates
- Technician certificates
- Summary

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Component Testing Plan

Developing Component Testing Plan

- List of systems and components to be commissioned
- Written commissioning plan
- Compile test data sheet and procedures for each component

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Functional Testing Plan

Developing Functional Testing Plan

- Develop functional test scripts and MOP's for testing based off of equipment installation manuals, site specific O&M manuals and start up checklists
- Provide functional test forms to contractors and vendors
- Define the roles of team members during testing
- Functional testing can only begin once component tests are complete

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Integrated System Tests

Developing Integrated System Tests

These are not always performed

- Integrated systems test plan includes all systems, electrical switchgear, generators, critical power, UPSs, HVAC, BMS, fire alarm & life safety systems
- Create a detailed testing script to exercise all systems under all conditions including a failure scenario for every component.

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Deliverables

Deliverables

- Completed package:
 - Summary of all testing performed
 - Testing results
 - O&M documents for tested equipment
 - Accurate as-built one-line
 - Owner training records
 - Schedule for maintenance activities

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- Why Cx An Existing Building
- Candidates for EBCx
- The EBCx Team
- Benefits of EBCx
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- Existing Building Cx Process
- Diagnostic Phase

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Beginning of Lesson 1


 **Reading Assignments:**

BCA Best Practices for Existing Building Commissioning
Retro-Cx Article - Dec 2009

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Existing Building Commissioning:

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Existing Building Cx

Existing Building Commissioning

Existing building Commissioning is a systematic process for investigating and optimizing the performance of building systems thru the implementation of Facility Improvement Measures to ensure building systems meet the current facility requirements.



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Retro-Commissioning

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EBCx Goals

- Improve comfort for occupants
- Extend the life of equipment
- Improve indoor air quality
- Improve effectiveness of O&M procedures
- Reduce energy bills
- Reduce energy consumption

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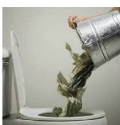
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Why Cx An Existing Building

Why Commission An Existing Building?


You Can't Manage What You Don't Measure:


"Most facility operators don't know their energy consumption compared to industry averages"



From the Owner's Perspective:

- Isn't my staff already doing this?
- Won't I need to replace equipment?
- My building may not be operating correctly?
- What if I'm going to sell my property?



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Candidates for EBCx

- Building Automation System
- HVAC Equipment is in good condition
- Never commissioned before
- 15 years old or younger
- Recent changes in tenant spaces
- Excessive thermal comfort complaints
- Multiple building portfolio



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The EBCx Team

```

    graph TD
      CA[Commissioning Authority] --> EBCT[Existing Building Commissioning Team]
      BMU[Building Manager and Users] --> EBCT
      OMS[Operations & Maintenance Staff] --> EBCT
      Owner --> EBCT
      Contractors --> EBCT
  
```

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Benefits of EBCx

- Average energy savings of 5-20%
- Reduced occupant complaints
- Properly trained O&M staff
- Increased net operating income
- Increased asset value
- Average Costs of RCx: \$0.15 to \$0.60 per Square Foot
- Value of Energy Savings: \$0.11 to \$0.72 per Square Foot
- Average payback of 2 years or less

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Reading Assignments:

- EPA Retro-Commissioning Guide
- Making Sense of RCx

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Existing Building Commissioning:

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Planning Phase

- Define Scope of Work
- Define project goals
- Define CFR
- Review documentation
- Benchmark Energy Performance
- Interview O&M and building occupant staff
- Develop EBCx plan
- Develop Building Operation Plan

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How to Get Started

Planning Phase: How to Get Started

- Brief walkthrough and system overview with RCx Provider
- Determine Facility Requirements
- Utility bill analysis and benchmarking
- Assessment of savings opportunities

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Investigation Phase

- Detailed site investigation
- Occupant Interviews
- Trends and Dataloggers
- Develop and Execute Performance Tests
- Master list of facility improvement measures(FIMss)
- Develop cost estimates for FIMs

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Common Issues Identified

Investigation Phase: Common Issues Identified

Design Deficiency

- Oversized Equipment
- Over Ventilation
- Improper Zoning
- Tenant Improvements

Maintenance Deficiency

- Failed Actuators/Sensors
- Missing Insulation
- Unmaintained Filters/Coils

Operational Deficiency

- Excessive Runtimes
- Simultaneous Heat/Cool
- Variable Loads/Constant Operation

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Implementation Phase

Implementation Phase

- Prioritize ECMs
- Plan for Implementation of selected ECMs for future projects
- Implement selected ECMs
- Verify successful ECM implementation
- Execute M&V Plan
- Create Ongoing Commissioning Plan

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Turnover Phase

Turnover Phase

- Update O&M and As-Built Documentation
- Develop Final Report
- Prepare Systems Manual
- Develop Training Plan
- Lessons Learned Meeting
- Approve Ongoing Commissioning Plan

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Operations/Persistence Phase

Operations / Persistence Phase

- Implement Ongoing Commissioning Plan
- Track Energy Consumption
- Review BAS Trending
- Implement Staff Training Plan
- Document operations changes with operators log

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Benefits of Retro-Cx

Maintaining the Benefits of Retro-Commissioning

Maintenance Staff Training should include:

- Continually monitoring energy usage
- Operating schedules and setpoint requirements
- Methods for identifying problems and deficiencies
- Accurate and complete operations manuals.

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The Existing Building Commissioning Process

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Reading Assignments:
Best Practices in Commissioning Existing Buildings – The Building Commissioning Association.

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Existing Building Commissioning:

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Creating The Commissioning Plan Process of Execution

```

graph LR
    A[Select RC's Provider] --> B[Confirm project goals and objectives with Provider]
    B --> C[Provider conducts interviews and performs facility walk-through]
    C --> D[Owner & Provider review findings to confirm building is a good candidate for RC's]
    D --> E[Provider submits Draft RC's Plan]
    E --> F[Owner reviews Provider's Draft RC's Plan]
    F --> G[Owner and Provider finalize RC's Plan]
    G --> H[Provider formally submits RC's Plan]
  
```

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The Existing Building Commissioning Plan

- General building information and owner contact information
- Goals and scope of the project
- Brief building and system descriptions, including a list of systems that will be investigated
- List of team members, their roles, responsibilities, and expected deliverables
- Description of the communication, reporting, and management protocols
- Schedule (for primary tasks)
- Documentation requests
- Investigation scope and methods
- Implementation Phase requirements
- Project hand-off Documentation Requirements

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Existing Building Commissioning Plan

- Continuously updated throughout the project
- Includes a list of expected project deliverables:
 - Findings log
 - Energy savings calculations
 - ROI calculations
 - LCCA
 - Implementation Plan
 - Building Operation Plan
 - Detailed scope of work document
 - FIM Implementation costs estimates
 - Training Material

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End of Lesson 3

Developing the Existing Building Commissioning Plan

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Reading Assignments:

- Continuous Commissioning Handbook
- ASHRAE March 2005 Article
- Sept 2011 Article in CSE magazine
- Sample RCx PECL case study
- EBCx Measure ASHRAE Article

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Common Issues Identified

Design Deficiency

- Oversized Equipment
- Over Ventilation
- Improper Zoning
- Tenant Improvements

Maintenance Deficiency

- Failed Actuators/Sensors
- Missing Insulation
- Unmaintained Filters/Coils

Operational Deficiency

- Excessive Runtimes
- Simultaneous Heat/Cool
- Variable Loads/Constant Operation

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ECRMs/ECMs and FIMs

Energy Cost Reduction Measures (ECRMs)

Energy Conservation Measures (ECMs)

Facility Improvement Measures (FIMs)

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Examples of ECRMs

Existing Building Commissioning

Examples of Energy Cost Reduction Measures (ECRMs)

Calculated Energy Savings, Project ROI < 1-2 Years

- Update HVAC controls programming for hours of occupancy
- Install Variable Frequency Drives
- Update Chilled/Condenser Water System Setpoints
- Update Lighting Fixtures
- Install occupancy sensors for Lighting
- Update AHU to ensure no simultaneous heating/cooling
- Survey and repair steam traps
- Reduce steam boiler supply pressure setpoint
- Repair condensate return pumps
- Replace pneumatic controls with digital controls
- Upgrade plumbing fixtures to low flow fixtures

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Examples of FIMs

Existing Building Commissioning

Examples of Facility Improvement Measures (FIMs)

Safety, Code Requirements, Cost Avoidance, No Proven Payback

- Ensure outdoor air ventilation rates achieved for each air handling unit.
- Test and Balance to ensure ventilation rates to patient areas
- Exhaust Fan balance to verify negative pressurization rooms.
- Conduct thorough firestopping above ceiling to complete fire/smoke walls.
- Clean Ductwork
- Upgrade/Replace outdated emergency power switchgear equipment.
- Add additional equipment to ensure redundancy.
- Upgrade fire alarm notification system.
- Replace equipment and piping that is near the end of it's useful life.
- Install backflow preventers on main domestic water line.
- Roofing Replacement

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Sample FIM

Facility Improvement Measure:

Install Occupancy Sensors for Lighting Control and Energy Efficiency

- Implementation Plan
- Impact to Occupants

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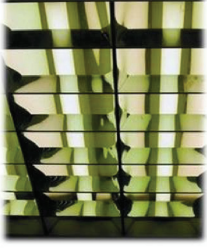
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Sample FIM



Facility Improvement Measure:
Replace Outdated Lighting (40-W T12 to 28-W T8)

- Implementation Plan
- Impact to Occupants

Savings Estimate Calculation

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Savings Calculation

Facility Improvement Measure:
Replace Outdated Lighting (40-W T12 to 28-W T8)

Savings Estimate Calculation:

- 40 Fixtures
- 4 lamps per fixture
- Operates 8 hrs per day 6 days per week
- Electric rate of \$.09/kWh
- Lamp kWh = # hrs per year operating * # lamps * # fixtures * lamp KW

Savings = \$431/yr

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Sample FIM



Facility Improvement Measure:
Adjust VAV Minimum and Maximum Airflow

- Implementation Plan
- Impact to Occupants

Savings Estimate Calculation

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Sample FIM



Facility Improvement Measure:
Demand Control Ventilation

- Implementation Plan
- Impact to Occupants

Savings Estimate Calculation:

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 - ☐ Savings Calculation
 - ☐ Sample FIM Cont..
 - ☐ Overall Benefits
 - ☐ End of Lesson 4
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Sample FIM



Facility Improvement Measure:
Update Exhaust Fan Controls & Hours of Operation

- Implementation Plan
- Impact to Occupants

Savings Estimate Calculation:

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Savings Calculation

Facility Improvement Measure:
Update Exhaust Fan Controls & Hours of Operation

Savings Estimate Calculation:

- 5 HP Exhaust Fan
- Currently operates 24/7
- Proposed occupancy schedule of only 12 hrs per day
- Exhaust Fan kWh = motor HP * .746 * .09/kWh * operating hrs per year

Calculated savings = \$209 per year


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Sample FIM Cont..

Sample FIM



Facility Improvement Measure:

Install Variable Frequency Drives (VFDs) on Chilled Water Pumps

- Implementation Plan
- Impact to Occupants

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Overall Benefits

Energy Savings
Vs.
Non-Energy Related Impacts

- Equipment Life
- Change Orders and Warranty Claims
- Liability
- Productivity
- Indoor Air Quality
- Thermal Comfort
- Ongoing Labor Cost
- Lost revenue


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End of Lesson 4



End of Lesson 4

Optimizing Systems and Example ECMs/FIMs & Savings Calculations

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Lesson 4.1

Beginning of Lesson 1

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Reading Assignments:

ASHRAE Nov. 2011 Article

ASHRAE Data Center Cx - April 2005

Part 1 - Health Facilities Commissioning Guidelines - ASHE

Lesson 1

Health Facility Commissioning

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Module 4

Lesson 4.1

Mission Critical Facility Cx

Mission Critical Facility Commissioning

High-tech facilities have, at times, been passed over in the quest for energy savings, often under the pretense that they "must" already be optimized or that they are mission critical and should not be disturbed. While it is true that these facilities receive a far higher level of quality assurance and optimization in construction and operation than traditional buildings, energy performance per se is often not a central focus.

~Evan Mills, ASHRAE Journal Nov 2011

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Module 4

Lesson 4.1

Mission Critical Facility Cx

Mission Critical Facilities Cont..

Mission Critical Facilities

Energy Intensive Facilities (i.e. Opportunity for Energy Savings)

24/7 Operation

High Air Change Rates & High Air Volumes

Critical Activities with Strict Parameters

System Redundancies

Excessive Cooling and/or Dehumidification

Safety Requirements and Emergency Backup

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Module 4

Lesson 4.1

Mission Critical Facility Cx

Mission Critical Facilities Cont..

Mission Critical Facilities

- Laboratories
- Specialized Research Centers
- Data Centers
- Cleanrooms
- Health Care Facilities
- Medical Centers

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Module 4

Lesson 4.1

Why are Health Facilities Different?

Why are Health Facilities Different?

- Life Supporting Facility
- Specialty Systems (Nurse Call, Code Blue, Medical Gas, Vacuum, Steam Sterilizers, Infection Control, etc.)
- Life Safety Requirements for Non-Abulatory Patients. (Pressurization, Fire Ratings, Smoke Barriers, Egress)
- Large Campuses, Interconnected, Multiple Age Systems
- The Joint Commission Inspections and Certifications
- Specialty Critical Care Spaces with Strict Environmental Parameters
 - Intensive Care Unit - MRI - Neonatal Units -Heart/Ortho - Operating Rooms - Negative Pressurization Rooms

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Module 4

Lesson 4.1

Systems and Equipment

Mission Critical Systems and Equipment

- Chilled Water Systems
 - Temperature control and dehumidification
 - Great Impact on energy costs
 - Facility must constantly provide flow and temperature
 - Higher efficiency at high load
 - Dynamic Load
- Steam and Heating Systems
 - Variable Loads: Humidification, Sterilization, Heating, Domestic Water, etc.
 - Emergency Power Required; Standby Capability Required
 - Must Satisfy dynamic load conditions
 - Ensure energy efficient controls (OAT reset schedule)
- Air Systems
 - High Air Changes - Filtration, Outside Air Requirements, Pressurization Requirements.
 - Life Safety: Smoke Evacuation and Stair Pressurization.
 - Complex Operation: Transfer to/from Emergency Power, Peak and Varying Loads; Standby and Redundant Modes Night Setback, Alarms and Overrides.

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- Mission Critical Facilities C
- Why are Health Facilities I
- Systems and Equipment
- Systems and Equipment C**

The Business of HFCx

LEED 2012 and HFCx

End of Lesson 1

Quiz

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- Team Structure
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Systems and Equipment Cont.

Mission Critical Systems and Equipment (Continued)

- Medical Gases & Medical Vacuum**
Unit Sizer, Main Electrical, Switchgear, and Distribution Installation and Coordination Study
Emergency System: Life Safety and Critical Branch Function, Transfer/Delay/Cooldown, Interface and Sequencing
Monitoring Systems
Fire Alarm Interface with many systems including HVAC, elevators, security, fire protection, doors, paging system, smoke evacuation, stair pressurization, and kitchen equipment.
Nurse Call
- Life Safety and Building Envelope**
Fire Resistant Ratings, Smoke Barriers, Smoke Evacuation and Pressurization Systems
Building Envelope (insulation, roofing, glazing barriers) have effect on internal systems.
- Electrical Systems**
Domestic Water Supply and Quality is critical (booster pumps, water softeners, heating)
Fire pump, jockey pump, sprinkler system, pre-action fire protection & dry fire protection.
- Plumbing & Fire Protection**
Requires Verification by Independent Certification.

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LEED 2012 and HFCx

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The Business of HFCx

$$\text{VALUE} = \frac{\text{BENEFITS}}{\text{COST}}$$

- Understanding the Owner and The "C" Team
- ROI
- VE

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LEED® 2012 and HFCx

- Public is seeing value in sustainable design and construction Initiatives
- Research shows correlation between facility and human wellness.
- There are challenges in achieving LEED® compliance for Healthcare

Rating System	Category
LEED for New Construction	GREEN BUILDING DESIGN & CONSTRUCTION
LEED for Core & Shell	
LEED for Schools	
LEED for Healthcare*	
LEED for Retail*	GREEN INTERIOR DESIGN & CONSTRUCTION
LEED for Commercial Interiors	
LEED for Retail Interiors*	
LEED for Existing Buildings	GREEN BUILDINGS OPERATIONS & MAINTENANCE
LEED for Existing Schools*	

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End of Lesson 1

Health Facility Commissioning

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Beginning of Lesson 2

UNIVERSITY OF Nebraska Lincoln

Reading Assignments:

Chapter 1 of Part 2 – Health Facilities Commissioning Guidelines – ASHE

Chapter 2 of Part 2 – Health Facilities Commissioning Guidelines – ASHE

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Health Facility Commissioning

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The HFCx Process

Pre-design Phase

Design Phase

Construction Phase

Occupancy & Operational Sustainability

Post Occupancy & Warranty

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PreDesign Phase

The HFCx Process – PreDesign Phase

Pre-design

Design

Construction

Occupancy

Warranty

- Establish Scope
- Define the Project Team Structure
- Select the CxA

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Phase Scope

The HFCx Process – PreDesign Phase

Pre-design

Design

Construction

Occupancy

Warranty

- Establish Scope

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Team Structure

The HFCx Process – PreDesign Phase

Pre-design

Design

Construction

Occupancy

Warranty

- Define the Project Team Structure

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The HCFx Process

The HFCx Process – PreDesign Phase

Hospital Administration and Staff

Design Team

CxA Support

Owners Project Manager

Project Manager

Lead Commissioning Authority

Facilities Department

General Contractor

Installing Contractors

- Define the Project Team Structure
- Define Lines of Communication
- Define Acceptance/ Approval Protocol

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Select the CxA

The HFCx Process – PreDesign Phase

- Select the CxA
 - Engage as early as possible
 - Qualifications
 - Selection Process

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Design Phase

The HFCx Process – Design Phase

- Define Energy Efficiency Goals
- OPR and BOD
- Cx Plan and Specs
- Design Reviews
- Review Sequences of Operation
- Utility Management Plan

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Goals

The HFCx Process – Design Phase

- Define Energy Efficiency Goals

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OPR & BOD

The HFCx Process – Design Phase

- Owners Project Requirements (OPR)
- Basis of Design (BOD)

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Documentation

The HFCx Process – Design Phase

- Commissioning Documentation
 - Commissioning Plan
 - Commissioning Specifications

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Design Reviews

The HFCx Process – Design Phase

- Design Reviews
 - Schematic Design Review
 - Design Development Review
 - Review of the Basis of Design
 - Construction Document Review

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Review Sequences of Operation

The HFCx Process – Design Phase

- **Review Sequences of Operation**
 - All HVAC Equipment
 - Ensure sufficient detail
 - Include all modes, alarms, schedules, tuning, trend requirements, adjustable and non-adjustable setpoints
 - Emergency/standby operation

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Utility Management Plan

The HFCx Process – Design Phase

- **Utility Management Plan**
 - Joint Commission Requirement

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End of Lesson 2

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End of Lesson 2

Design and Predesign Phase

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 - Fire/Smoke Damper

Beginning of Lesson 3

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Reading Assignments:
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Lesson 3

Health Facility Commissioning

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The HFCx Process

Pre-design Phase

Design Phase

Construction Phase

Occupancy & Operational Sustainability

Post Occupancy & Warranty

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Meetings

The HFCx Process – Construction Phase

Pre-design

Design

Construction

Occupancy

Warranty

- Commissioning Conference and Commissioning Meetings
- Inclusion of all team members

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Issues Log

The HFCx Process – Construction Phase

Pre-design

Design

Construction

Occupancy

Warranty

- Issues Log
- Continued from design phase
- Records progress and resolution path
- Discussed with team on regular basis thru resolution

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Documentation Review

The HFCx Process – Construction Phase

Pre-design

Design

Construction

Occupancy

Warranty

- Documentation Review
- Equipment and Product Submittals
- Shop Drawings
- Coordination Drawings
- Operations & Maintenance Manuals
- O&M Training Plan
- TAB Report
- As-Built Record Drawings

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Checklists and Inspections

The HFCx Process – Construction Phase

Pre-design

Design

Construction

Occupancy

Warranty

- Prefunctional Checklists and Inspections

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Equipment and Start-Up

The HFCx Process – Construction Phase

```

    graph TD
      A[Pre-design] --> B[Design]
      B --> C[Construction]
      C --> D[Occupancy]
      D --> E[Warranty]
  
```

- Witness Equipment and Systems Start-Up
- Manufacturer Startups
- Required Contractor Testing

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Testing

The HFCx Process – Construction Phase

```

    graph TD
      A[Pre-design] --> B[Design]
      B --> C[Construction]
      C --> D[Occupancy]
      D --> E[Warranty]
  
```

- Functional Performance Testing
- Direct, Witness, and Document
- Component to System Level
- Integrated Systems Testing
- Seasonal Testing
- Retesting

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End of Lesson 3 Construction Phase

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Reading Assignments:
Chapter 4 of Part 2 – Health Facilities Commissioning Guidelines - ASHE

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Health Facility Commissioning

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The HFCx Process

The HFCx Process

Pre-design Phase

Design Phase

Construction Phase

Occupancy & Operational Sustainability

Post Occupancy & Warranty

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Staff Training

The HFCx Process – Occupancy and Operational Sustainability

Pre-design

Design

Construction

Occupancy

Warranty

- Operations & Maintenance Staff Training
 - Training Agenda
 - Contractor Training Plan
 - Videotaping
 - Complete O&M Manuals

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HVAC Control System

The HFCx Process – Occupancy and Operational Sustainability

Pre-design

Design

Construction

Occupancy

Warranty

- HVAC Control System
 - Complete and Accurate Graphics and Point-to-Point
 - Setpoints and Current Measured Values
 - Alarms
 - Trending Requirements and Analysis by Maintenance Staff

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Report and Systems Manual

The HFCx Process – Occupancy and Operational Sustainability

Pre-design

Design

Construction

Occupancy

Warranty

- Commissioning Report and Systems Manual

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Fire/Smoke Damper

The HFCx Process – Occupancy and Operational Sustainability

Pre-design

Design

Construction

Occupancy

Warranty

- Fire/Smoke Damper Testing and Inspection Plan

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Final UMP and SOC Documentation

The HFCx Process – Occupancy and Operational Sustainability

- Final UMP and SOC Documentation
- Verify final documents are complete and available for O&M staff and for review by the Joint Commission:
 - Utility Management Plan
 - Statement of Conditions

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BMP

The HFCx Process – Occupancy and Operational Sustainability

- Building Maintenance Program (BMP)

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Occupancy Phase

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Reading Assignments:
Chapter 5 of Part 2 – Health Facilities Commissioning Guidelines - ASHRAE

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Health Facility Commissioning

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The HFCx Process

Pre-design Phase

Design Phase

Construction Phase

Occupancy & Operational Sustainability

Post Occupancy & Warranty

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Review of System Operation

The HFCx Process – Post Occupancy and Warranty

Pre-design

Design

Construction

Occupancy

Warranty

- Review of System Operation thru Trend Data
- Review concerns and discrepancies before they are identified by occupants.

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Energy and Performance

The HFCx Process – Post Occupancy and Warranty

Pre-design

Design

Construction

Occupancy

Warranty

- Measure and Verify Actual Energy Performance and Benchmark
- EPA Energy Star Website and/or facility worksheets.
- Compare Projected to Actual
- Review discrepancies

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Post-Occupancy Testing

The HFCx Process – Post Occupancy and Warranty

Pre-design

Design

Construction

Occupancy

Warranty

- Conduct Post-Occupancy Performance Testing
- Peak Loads
- Seasonal Loads
- Integrated Systems

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End-of-Warranty Review

The HFCx Process – Post Occupancy and Warranty

Pre-design

Design


Construction

Occupancy

Warranty

- End-of-Warranty Review
- 8-10 Months past Substantial Completion
- Identify outstanding issues for correction under warranty.

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Reading Assignments:

Chapter 8 of Part 2 – Health Facilities Commissioning Guidelines – ASHE

EPA Lab Retro-Commissioning Bulletin

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Health Facility Commissioning

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Planning

Heath Facility R-Cx Process

Planning

Investigation

Implementation

Turnover

Operations

- Document Energy Consumption History (Utility Bills and Metering)
- Establish ReCx Plan, Cx Team, and 'Current Facility Requirements'
- Collect Facility Drawings, TAB Reports, Trends, and Controls SOO.

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Investigation

Heath Facility R-Cx Process

Planning

Investigation

Implementation

Turnover

Operations

- Survey Complete Facility; Interview Occupants and O&M Staff
- Conduct Testing as safely permitted
- Utilize dataloggers and meters to measure performance and verify operating parameters
- Investigate and finalize Facility Improvement Measures (FIMs).
- Document compliance and discrepancies to the CFR

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Implementation

Heath Facility R-Cx Process

Planning

Investigation

Implementation

Turnover

Operations

- Implement Sequence Changes, Occupancy Schedules, and Equipment Upgrades
- Implement Code Compliance, Cost Avoidance, and Occupant Safety Measures

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Turnover and Operations

Heath Facility R-Cx Process

Planning

Investigation

Implementation

Turnover

Operations

- Document Savings thru ongoing Monitoring and Verification
- Ensure O&M staff understands and is trained on implementation of ongoing efforts
- Ensure final documentation is complete.

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ECRMs Vs. FIMs

Mission Critical Facility Retro-Commissioning

Energy Cost Reduction Measures (ECRMs)

VS.

Facility Improvement Measures (FIMs)

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ECRMs

Mission Critical Facility Retro-Commissioning

Examples of Energy Cost Reduction Measures (ECRMs)

Calculated Energy Savings, Project ROI < 1-2 Years

- Update HVAC controls programming for hours of occupancy
- Install Variable Frequency Drives
- Update Chilled/Condenser Water System Setpoints
- Update Lighting Fixtures
- Install occupancy sensors for Lighting
- Update AHU to ensure no simultaneous heating/cooling
- Survey and repair steam traps
- Reduce steam boiler supply pressure setpoint
- Repair condensate return pumps
- Replace pneumatic controls with digital controls
- Upgrade plumbing fixtures to low flow fixtures



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FIMs

Mission Critical Facility Retro-Commissioning

Examples of Facility Improvement Measures (FIMs)

Safety, Code Requirements, Cost Avoidance, No Proven Payback

- Ensure outdoor air ventilation rates achieved for each air handling unit.
- Test and Balance to ensure ventilation rates to patient areas
- Exhaust Fan balance to verify negative pressurization rooms.
- Conduct thorough firestopping above ceiling to complete fire/smoke walls.
- Clean Ductwork
- Upgrade/Replace outdated emergency power switchgear equipment.
- Add additional equipment to ensure redundancy.
- Upgrade fire alarm notification system.
- Replace equipment and piping that is near the end of it's useful life.
- Install backflow preventers on main domestic water line.
- Roofing Replacement




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End of Lesson 6



End of Lesson 6 Mission Critical Facility Retro-Commissioning





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LECTURE 1

Building Envelope

Background

- Homes consume 22% of total U.S. energy production
- All buildings accounts for over 49% of total U.S. energy consumption

Source: EIA 2011

What are included in the Building Envelope?

- The interface between the interior of the building and the outdoor environment
- Including the walls, slabs, roof, and foundation



Picture from EPA Energy Star website

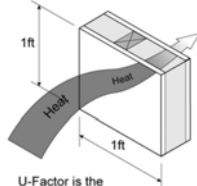
Source: <http://www.c2es.org/>

The roles of the building envelope

- Plays an important role in determining the amount of energy necessary to maintain a comfortable indoor environment
- The more insulation and tighter a building envelope, the less energy needed for a building
- Controls
 - Heat Transfer
 - Moisture movement
 - Airflow and pressure

Heat Transfer though Building Envelope

- U-factor
- R-values
- Thermal mass



U-Factor is the rate of heat flow in Btu/h through one ft² area when one side is 1°F warmer

Picture from <http://www.advancedbuildings.net/>

Heat Transfer though Building Envelope

- U-factor
- R-values
- Thermal mass



Picture from <http://energy.gov/energysaver/articles/insulation>

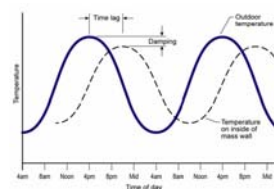
R-Values

Climate Zone	Ceiling R-value	Wood Frame Wall R-Value	Floor R-value	Basement Wall R-Value	Slab R-Value & Depth	Crawl Space R-Value
1	30	13	13	0	0	0
2	30	13	13	0	0	0
3	30	13	19	0	0	5/13
4 except Marine	38	13	19	10/13	10, 2ft	10/13
5 and Marine 4	38	19 or 13+5	30	10/13	10, 2ft	10/13
6	49	19 or 13+5	30	10/13	10, 4ft	10/13
7 and 8	49	21	30	10/13	10, 4ft	10/13

Table from Energy Star Qualified Homes Codes & Standard

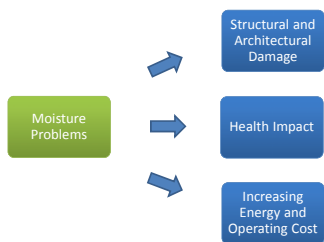
Heat Transfer through Building Envelope

- U-factor
- R-values
- Thermal mass



Picture from <http://www.advancedbuildings.net/>

Moisture Control



Moisture Control

- Install vapor barriers on the warm, moist side of framed walls, doors and roofs
- Provide adequate ventilation in attics, crawl space, wall cavities
- Consider installing continuous a 3-6 mil vapor barrier under the slab which in immediate contacts with the ground
- Proper design and installation of roof flashing, pan flashing for windows and doors, capillary breaks for footings, and other areas where moisture can enter the building envelope.

Source: <http://www.epa.gov/iaq/schooldesign/moisturecontrol.html>



Picture from <http://www.etietc.com/>

Air Leakage

Strategies for reducing air leakage:

- Continuous air barrier on roof and walls
- Windows/doors with low rates of infiltration
- Weather-stripping
- Using air lock entries in cold climates

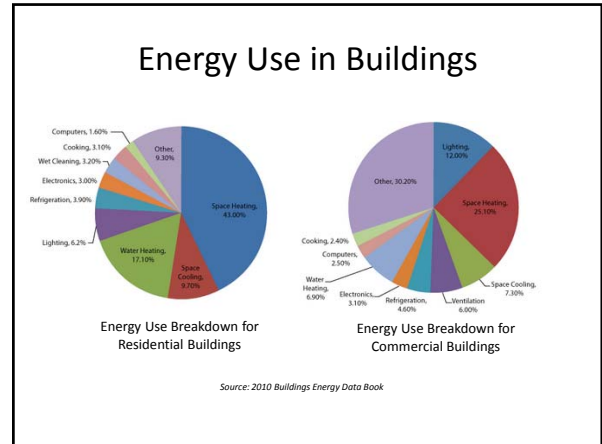


Sources of Air leaks in a Single-Family House (Source: DOE-Tips on Saving Money & Energy at Home 2011)

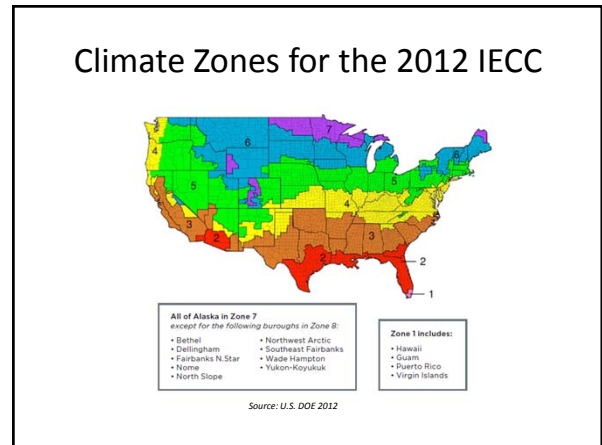
source: <http://www.michigan.gov>

LECTURE 2

Energy-efficient Building Envelope Design



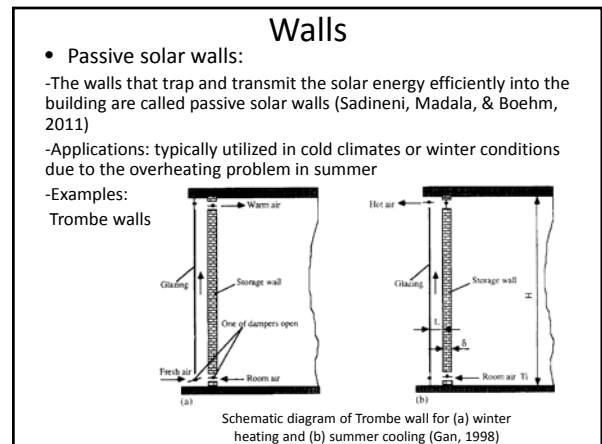
- ### Properties of Energy-efficient Building Facades
- Allowing daylight into a building
 - Preventing unwanted solar heat
 - Preventing air or moisture from passing through the façade
 - Allowing natural ventilation to cool the building's interior (Aksamija, Aja. 2013)



Climate-Based Design

Climate type	Design strategies for sustainable facades
Heating-dominated climates Zone 5,6,7,8	<p>Solar collection and passive heating: collection of solar heat through the building envelope</p> <p>Heat storage: storage of heat in the mass of the walls</p> <p>Heat conservation: preservation of heat within the building through improved insulation</p> <p>Daylight: use of natural light sources and increased glazed areas of the façade, use of high-performance glass, and use of light shelves to redirect light into interior spaces</p>
Cooling-dominated climates Zone 1,2,3	<p>Solar control: protection of the façade from direct solar radiation through self-shading methods (building form) or shading devices</p> <p>Reduction of external heat gains: protection from solar heat gain by infiltration (by using well-insulated opaque façade elements) or conduction (by using shading devices)</p> <p>Cooling: use of natural ventilation where environmental characteristics and building function permit</p> <p>Daylight: use of natural light sources while minimizing solar heat gain through use of shading devices and light shelves</p>
Mixed climates Zone 4	<p>Solar control: protection of façade from direct solar radiation (shading) during warm seasons</p> <p>Solar collection and passive heating: solar collection during cold seasons</p> <p>Daylight: use of natural light sources and increased glazed areas of the façade with shading devices</p>

(Aksamija, Aja. 2013)



Walls

- Lightweight concrete (LWC) walls (Sadineni, Madala, & Boehm, 2011):

-Lightweight concrete (LWC) refers to any concrete produced with a density of less than 2000 Kg/m³

-The thermal resistance can be improved by mixing with light weight aggregates, such as pumice, diatomic, foamed slag, sintered pulverized fuel ash

-Applications: useful in countries or districts where concrete construction is predominant and the use of insulation in walls is not a common practice

-Advantages: Lightweight
 Good thermal performance
 Can be constructed faster using less skilled labor

Walls

- Ventilated masonry walls/cavity walls (Sadineni, Madala, & Boehm, 2011):

-An air gap between two layers of masonry wall braced with metal ties

-Two basic types: (1) with forced ventilation in the cavity (2) with natural ventilation (stack effect)

-Applications: most commonly are used to enhance the passive cooling of buildings. A typical summer cooling energy saving of 40% can be achieved with carefully designed ventilated walls

-According to the related research, the energy savings increase with the increase in width of the air gap (diminishing returns over 0.15m)

Walls

- Walls with latent heat storage (Aksamija, Ajla 2013):

-Phase change materials (PCMs) is incorporated in light weight porous material, such as gypsum or concrete materials

-PCMs are solid at room temperatures, but liquefy at higher temperatures, absorbing and storing heat in the process.

-Applications:
 Cooling of heat and thermal storage
 PCMs can absorb high exterior temperatures during the day and dissipate the heat to the interior at night

Fenestration

- Fenestration components include windows, curtain walls, clerestories, skylights and etc.
- Plays a vital role in providing thermal comfort and optimum illumination levels in a building (Sadineni, Madala, & Boehm, 2011)
- An important metric of a façade’s characteristic: Window-to-wall ratio (WWR)
 - Higher WWRs result in greater energy consumption (Aksamija, Ajla 2013)

Fenestration

- Aerogel glazing
 -Aerogels are synthetic solids that consist almost entirely of air (typically 90-99.8% air by volume) (Sadineni, Madala, & Boehm, 2011)



-Advantages: High performance
 Low density
 Outstanding light diffusing properties

-Applications:
 Can be viewed as potentially providing performance benefits across more than one area (Bahaj, James, & Jentsch, 2008).

Fenestration

- Vacuum glazing (Sadineni, Madala, & Boehm, 2011)

-Vacuum space is created between two glass panes to eliminate the conductive and convective heat transfers between the glass panes.

-Low-e coating is often applied on one or both of the glass panes to reduce the re-radiation into the indoor space

-Can achieve U-values of less than 0.1 Btu/hr-ft²-°F

-Faces some challenges in maintaining vacuum for longer periods

-Applications: where requires high insulation level glazing

Fenestration

- Emerging glazing technologies
- Examples: Switchable reflective glazing, Suspended particle devices (SPD) films, Holographic optical elements
- Faces some challenges in cost, warranty, life time, clearness issues which thwart the marketability (Sadineni, Madala, & Boehm, 2011).

Roofs

- Reinforced cement concrete roofs (Sadineni, Madala, & Boehm, 2011)

Advantages: pest resistance, natural calamity resistance, availability, cost effectiveness of concrete ingredients

Disadvantages: unfavorable thermal characteristic during tropical summers

Improvements: employing roof shading, cool roof coating or compound roof systems

- Applications: useful in countries or districts (such as South Asia and the Middle East) where concrete construction is predominant

Roofs

- Lightweight roofs (Lightweight aluminum standing seam roofs) (Sadineni, Madala, & Boehm, 2011)
- Popular applications on commercial and government buildings

Advantages: lightweight, economical

Disadvantages: wind sensitive, bad thermal characteristic

Improvements: adding thermal insulation, using light colored roof paint

Roofs

- Ventilated roofs (Sadineni, Madala, & Boehm, 2011)
- Two slabs delimiting a duct through which air flows
- Types:
 - (1) passive type (stack effect)
 - (2) active type (fan induced ventilation)
- Advantages:
 - Great energy savings compared to non-ventilated roofs during summer
- Applications:
 - Popular in hot climatic conditions
 - Particularly useful in moderate height and wide roof area buildings

Roofs

- Vaulted and domed roofs

Large beam component of the solar radiation which is effectively reflected by the curved roof surface

Suitable for hot and dry climates

- The half rim angle of a VR should be greater than 50° to show favorable influence on the indoor thermal conditions
- South-north orientation of vaulted roof is proved to be more advantageous than east-west orientation
- Applications: popular in the areas where the climatic conditions are hot and arid

Roofs

- Solar-reflective/cool roofs (Sadineni, Madala, & Boehm, 2011)
- High solar reflectance and high infrared remittance roofs
- Maintain lower roof surface temperature and inhibit the heat conduction into the building: increase only 5–14 °C (10–25 °F) above ambient temperature during the day, while the surface of a black roof can increase in temperature as much as 50 °C (90 °F)
- Advantages: (1) Extended service life of roofs (2) Economical for retrofitting (3) Achieve cooling load savings of 5-40%
- Applications: In some regions, cool roofs are required by legislation. Voluntary programs may also encourage building owners to pursue cool roofs (Elie Tawil, 2010)

Roofs

- Green roofs ((Sadineni, Madala, & Boehm, 2011))
- A green roof composite system consists of a waterproofing membrane, growing medium and vegetation layer.
- Types:
 - (1) extensive green roof (with thinner substrate layer) → allows to grow low level planting such as lawn or sedum
 - Applications: can be retrofitted easily on existing roofs and requires minimum maintenance
 - (2) intensive green roof(with deeper substrate layer) → allows to cultivate deep rooting plants such as shrubs and trees
- Advantages: Reflect solar radiation
Act as an extra thermal insulation layer
Reduce storm water run off
Increase agricultural space

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LECTURE 3

Thermal Insulation and Airtightness of the Building Envelope

Thermal Insulation

- Thermal insulation is a material or combination of materials, that, when properly applied, retard the rate of heat flow by conduction, convection, and radiation. It retards heat flow into or out of a building due to its high thermal resistance (ASHRAE, 2001; Al-Homoud & Mohammad, 2005).

Benefits of Using Thermal Insulation

- Energy conservation
 - Economic benefits
 - Environmental benefits
 - Thermally comfortable buildings
 - Reduced noise levels
 - Building structural integrity
 - Vapor condensation prevention
 - Fire protection
- (Al-Homoud & Mohammad, 2005)

Classification of the Most Used Insulating Materials

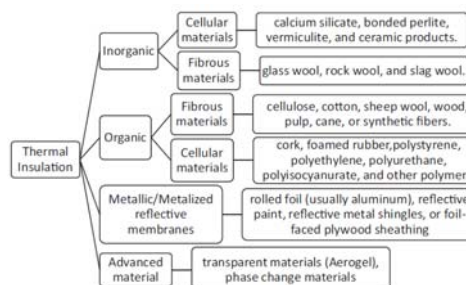


Figure from (Sadineni, Madala, & Boehm, 2011)

The Selection Criteria for Thermal Insulation

- Thermal performance
 - Cost
 - Ease of construction
 - Building codes requirements (safety and health issues)
 - Durability
 - Acoustical performance
 - Air tightness
 - Environmental impact
 - Availability
- (Al-Homoud & Mohammad, 2005)

The Best Location of Thermal Insulation

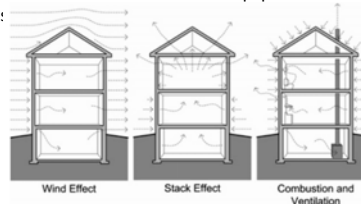
- Placing insulation closest to the surface of heat entry (Sadineni, Madala, & Boehm, 2011)
 - In space heating load dominant regions: close to the inner surface of the building envelope
 - In cooling dominant regions: close to the outer surface
- Insulation placement in the middle can provide even distribution in the component (Al-Homoud & Mohammad, 2005)

Airtightness of the Building Envelope

- Air leakage/Infiltration: the movement of air into the conditioned space of a building through cracks, leaks, or other building envelope openings (Sadineni, Madala, & Boehm, 2011)
- The impacts of the air leakage (Younes, Shdid, & Bitsuamlak, 2011):
 - Increases energy consumption
 - Affects the thermal comfort in the building
 - Impacts the indoor air quality and the distribution of indoor air pollutants
 - Impacts the long-term performance of the building material and the building's structural integrity
- Tightening the building envelope with caulking and sealants has positive impacts on the energy performance of the building (U.S. DOE, 2012)

Airtightness of the Building Envelope

- Factors affecting infiltration (Sadineni, Madala, & Boehm, 2011)
 - Temperature difference between indoor and outdoor air (stack effect)
 - Wind pressure
 - Operation of mechanical ventilation equipment and vented combu:



Source: Building Science Corporation, www.buildingscience.com

Airtightness of the Building Envelope

- IECC requirements

Climate Zone	2009 IECC	2012 IECC
1-2	< 7 ACH	≤ 5 ACH@ 50 pascals
3-8	< 7 ACH @ 50 pascals	≤ 3 ACH@ 50 pascals

Sources: 2009 IECC & 2012 IECC



Climate Zones (by County) for the 2012 IECC

Airtightness of the Building Envelope

Air Leakage Calculating Technologies (Younes, Shdid, & Bitsuamlak, 2011):

- Empirical techniques
 - Usually only used for evaluating existing buildings
 - Include air change methods, reduction of pressurization test, regression methods, and etc.
- Theoretical methods
 - Allows researchers to give evaluations when it is not possible to use empirical methods
 - Include single-zone, multi-zone and computational fluid dynamics (CFD) models

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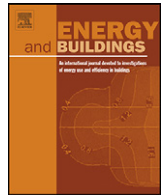
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Appendix B: Journal Paper



Numerical simulation of buoyancy-driven turbulent ventilation in attic space under winter conditions

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ABSTRACT

Attic design and construction have significant impacts on residential buildings' energy performance. In order to understand how passive ventilation rates affect ridge-vent attic's performance, a two-dimensional steady-state finite volume model is employed to simulate the buoyancy-driven turbulent ventilation and heat transfer in a triangular attic space of a gable-roof residential building under winter conditions. The modeled attic has a pitch of 5/12 and a passive ventilation system, consisting of continuous ridge and soffit vents. The v2f model is used to analyze the turbulent air flow and natural convection heat transfer inside the attic. The effects of ambient air temperature, vent size, and ceiling insulation on heating load and ice dam formation are investigated. The thermal performance of the vented attic is compared with a sealed attic as well. The simulation results reveal that symmetrical air flow patterns exist in a vented attic, in contrast to the asymmetrical air flow patterns found in a sealed attic. In addition, it is suggested that increasing vent size results in higher ventilation air flow rate but barely affects the attic heating load, and that both sufficient ventilation and insulation are needed to ensure the proper functions of the attic and its energy efficiency.

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1. Introduction

Attic ventilation has been a prevailing practice in roof construction in the United States since 1940s [1]. For decades, the ASHRAE Handbook-Fundamentals has included recommendations for attic ventilation in residential roof construction, in order to (i) minimize condensation on the underside of roof sheathing, (ii) cool attic air during summer time, (iii) prevent ice dams during winter time, and (iv) extend the service life of the roof materials [2]. Almost all the existing building codes across the United States (e.g., the BOCA National Building Code, International Building Code, Standard Building Code, and Uniform Building Code) require attic spaces to be ventilated. Typically, the net free vent area (unobstructed area where air can freely flow from outside to inside to outside) is required to be 1/150 of the floor area of the attic space being ventilated, and a reduction of the ventilation ratio from 1/150 to 1/300 is allowed only if at least 50% of the ventilating area is in the upper portion of the space and a continuous vapor retarder is installed on the warm side of the ceiling in cold climates [3].

Despite these long-established guidelines for attic ventilation in residential building construction and retrofit, the technical data used to derive these ventilation requirements are very limited [2].

Recent research (e.g., [2,4]) has suggested that the advantages and disadvantages of providing attic ventilation need to be evaluated on a case-by-case basis, i.e., ventilation should be treated as a design option instead of a universal requirement.

The objective of this paper is to quantitatively investigate the impact of attic ventilation rates and ceiling insulation types on the attic performances of gable-roof houses, and to provide technical data for future guidelines. The focus of the paper is to employ a computational fluid dynamics (CFD) model to study the turbulent air flow and heat transfer in both sealed and vented attics.

The majority of the previous research on heat transfer in attic spaces is concerned with natural convection in triangular enclosures, as reviewed by Kamiyo et al. [5]. While a considerable number of experimental and numerical studies (e.g., [6–15]) have been devoted to the analysis of flow and heat transfer under laminar conditions, only a few studies (e.g., [16,17]) investigated turbulent flow and heat transfer. For realistic sizes of residential attics, the air flow is almost always in the turbulent regime.

Air flow and heat transfer in vented attic spaces have been scarcely investigated in the past. Medina et al. [18,19] developed a transient model for residential attics based on empirical heat transfer correlations and reported that the cumulative difference between the model predictions and experimental data was less than 12%. However, in this correlation-based model, neither air flow velocity nor temperature distribution in the attic space was solved. Moujaes and Alsaiegh [20] developed a two-dimensional

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Nomenclature

c_p	specific heat, $\text{J kg}^{-1} \text{K}^{-1}$
f	elliptic relaxation function
g	gravitational acceleration, m s^{-2}
h_c	heat transfer coefficient at ceiling, $\text{W m}^{-2} \text{K}^{-1}$
h_r	heat transfer coefficient at roof, $\text{W m}^{-2} \text{K}^{-1}$
k	turbulence kinetic energy, $\text{m}^2 \text{s}^{-2}$
L	turbulence length scale, m
p	pressure, N m^{-2}
p_{atm}	atmospheric pressure, N m^{-2}
S	strain rate, s^{-1}
t_r	roof thickness, m
T	temperature, K
T_0	reference temperature, K
T_{cb}	temperature at ceiling-bottom, K
T_{rt}	temperature at roof-top, K
T_{in}	inlet air temperature, K
u	velocity component, m/s
$\overline{v^2}$	turbulence velocity variance scale, $\text{m}^2 \text{s}^{-2}$
x, y	coordinates, m

Greek symbols

β	thermal expansion coefficient, K^{-1}
ε	turbulence dissipation rate, $\text{m}^2 \text{s}^{-3}$
λ	thermal conductivity, $\text{W m}^{-1} \text{K}^{-1}$
λ_r	roof thermal conductivity, $\text{W m}^{-1} \text{K}^{-1}$
μ	molecular viscosity, $\text{kg m}^{-1} \text{s}^{-1}$
μ_t	eddy viscosity, $\text{kg m}^{-1} \text{s}^{-1}$
ρ	density, kg m^{-3}
σ_k	effective turbulence Prandtl number for k
σ_ε	effective turbulence Prandtl number for ε
σ_T	effective turbulence Prandtl number for T
τ	turbulence time scale, s

steady-state finite element model to simulate the thermal effects of placing a radiant barrier system inside a vented residential attic for a summer weather condition in Las Vegas. They employed the k - ε model to approximate the turbulent flow and heat transfer, and found that the use of attic radiant barrier system can reduce the ceiling cooling load by 25–30%. In their study, inlet air velocity was specified to vary between 0.2 m/s and 0.3 m/s, accounting for both the stack effect (air movement driven by buoyancy) and the wind effect, while the individual contribution of the stack effect was not isolated. In addition, the soffit vents of 10 cm and the ridge vent of 40 cm assumed in the model (corresponding to a ventilation ratio of 1/13) seem to be much larger than those adopted in the realistic buildings per building codes.

In this paper, a two-dimensional steady-state finite volume model is employed to simulate the buoyancy-driven turbulent ventilation and heat transfer in a triangular attic space of a gable-roof residential building under winter conditions. The turbulent air flow and natural convection heat transfer inside the attic is modeled in terms of the v2f model [21–23]. The v2f model is an eddy-viscosity model similar to the standard k - ε model, but incorporates near-wall turbulence anisotropy and non-local pressure-strain effects. It is a general low-Reynolds number turbulence model that is valid all the way up to solid walls, and therefore does not need to make use of wall functions. Previous studies (e.g., [24–26]) have shown that the v2f model performs the best among the Reynolds-averaged Navier–Stokes (RANS) models for indoor air flow simulations. In terms of the CFD model, the impacts of ambient air temperature, vent size, and ceiling insulation on heating load and ice dam

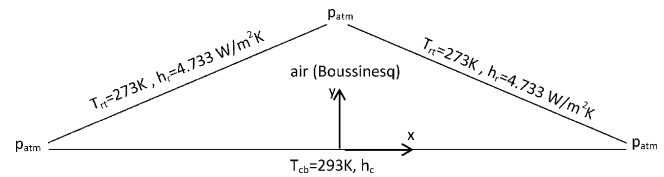


Fig. 1. Schematic of the computational domain and boundary conditions.

formation will be investigated in detail. The thermal performance of the vented attic will be compared with a sealed attic as well.

2. Numerical model

A schematic diagram of a cross-section plan of the physical model is shown in Fig. 1. In the direction perpendicular to the cross-section shown in Fig. 1, it is assumed that the building is long enough to ignore the effects of the gable walls, and thus the problem can be simplified to two-dimensional. The modeled attic space has a ceiling width of 8 m and a pitch of 5/12, corresponding to a pitch angle of 22.62°. For simplicity, no trusses have been included in the model, and the computational domain is only occupied by air. Furthermore, the air is assumed to be a Boussinesq fluid with a reference temperature that is always specified to the outside ambient air temperature to correctly calculate the buoyancy effects.

In order to correctly account for the thermal resistances of the ceiling and roofs, which are excluded from the computational domain, convection-type boundary conditions are applied to both the roof and ceiling boundaries. For example, energy balance across the roof thickness gives

$$\lambda \frac{\partial T}{\partial y} = \frac{\lambda_r}{t_r} (T - T_{\text{rt}}) = h_r (T - T_{\text{rt}}) \quad (1)$$

where T_{rt} is the temperature at the roof-top, and the heat transfer coefficient h_r is the reciprocal of the roof thermal resistance.

In this study, a roof-top temperature of 273 K and a heat transfer coefficient of 4.73 $\text{W/m}^2 \text{K}$ are specified to the roof boundaries to simulate a condition of a 3 cm plywood roof covered by snow. For investigating ice dam formation, which is a major objective of this study, a fixed roof-top temperature of 273 K is a reasonable approximation to the real situation, due to the large latent heat related to ice melting or water solidification. It should be noted that in cold climates, the roof-top temperature could be much lower than 273 K, even covered by snow, but that is not the case studied here. Similarly, a ceiling-bottom temperature of 293 K and a heat transfer coefficient depending on ceiling insulation are specified to the ceiling boundary. The ceiling insulation, expressed by the R -value, is a parameter that is allowed to assume different values for different investigated cases.

The vent size and inlet air temperature are two other parameters that are allowed to vary for different cases, in addition to the ceiling insulation. For all the cases investigated in this study, balanced vent areas are assumed, i.e., the left soffit vent has the same size as the right soffit vent, and the ridge vent has an area equal to the sum of the soffit vents. Pressures at the soffit and ridge vents are all specified to be zero gauge pressure and no velocities are specified in the model. Therefore, the obtained air flow is purely driven by the thermally induced buoyancy forces, i.e., the stack effect.

Following the Reynolds-averaged approaches to turbulence, all of the unsteadiness is averaged out, i.e., all unsteadiness is regarded as part of the turbulence [27]. As a result, the time-averaged air velocity, pressure, and temperature distributions in the attic space

shown in Fig. 1 are governed by the following steady-state continuity, momentum, and energy equations:

$$\frac{\partial}{\partial x_i}(\rho u_i) = 0 \quad (2)$$

$$\frac{\partial}{\partial x_j}(\rho u_i u_j) = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}[(\mu + \mu_t)S_{ij}] - \rho g_i \beta(T - T_0) \quad (3)$$

$$\frac{\partial}{\partial x_i}(\rho c_p T u_i) = \frac{\partial}{\partial x_j} \left[\left(\lambda + \frac{c_p \mu_t}{\sigma_T} \right) \frac{\partial T}{\partial x_j} \right] \quad (4)$$

According to the v2f model [21–23], the eddy viscosity, μ_t , is defined by

$$\mu_t = C_\mu \rho \bar{v}^2 \tau \quad (5)$$

and determined from the following transport equations for the turbulence kinetic energy, dissipation rate, velocity variance scale, and elliptic relaxation function:

$$\frac{\partial}{\partial x_i}(\rho k u_i) = P - \rho \varepsilon + \frac{\partial}{\partial x_j} \left[\left(\mu + \frac{\mu_t}{\sigma_k} \right) \frac{\partial k}{\partial x_j} \right] \quad (6)$$

$$\begin{aligned} \frac{\partial}{\partial x_i}(\rho \varepsilon u_i) = & \frac{C_{\varepsilon 1}(1 + 0.045 \sqrt{k/\bar{v}^2})P - C_{\varepsilon 2} \rho \varepsilon}{\tau} \\ & + \frac{\partial}{\partial x_j} \left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon} \right) \frac{\partial \varepsilon}{\partial x_j} \right] \end{aligned} \quad (7)$$

$$\frac{\partial}{\partial x_i}(\rho \bar{v}^2 u_i) = \rho k f - 6 \rho \bar{v}^2 \frac{\varepsilon}{k} + \frac{\partial}{\partial x_j} \left[\left(\mu + \frac{\mu_t}{\sigma_k} \right) \frac{\partial \bar{v}^2}{\partial x_j} \right] \quad (8)$$

$$f - L^2 \frac{\partial^2 f}{\partial x_j^2} = (C_1 - 1) \frac{(2/3 - \bar{v}^2/k)}{\tau} + C_2 \frac{P}{\rho k} + \frac{5\bar{v}^2 k}{\tau} \quad (9)$$

where

$$P = 2\mu_t S_{ij} S_{ij} \quad (10)$$

$$S_{ij} = \frac{1}{2} \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) \quad (11)$$

and the turbulence time scale and length scale are defined by

$$\tau = \min \left[\max \left(\frac{k}{\varepsilon}, 6 \sqrt{\frac{\mu}{\rho \varepsilon}} \right), \frac{\alpha}{\sqrt{3}} \frac{k^{3/2}}{\bar{v}^2 C_\mu \sqrt{2S_{ij} S_{ij}}} \right] \quad (12)$$

$$L = C_L \max \left[\min \left(\frac{k^{3/2}}{\varepsilon}, \frac{k^{3/2}}{\bar{v}^2 C_\mu \sqrt{6S_{ij} S_{ij}}} \right), C_\eta \left(\frac{\mu^3}{\rho^3 \varepsilon} \right)^{1/4} \right] \quad (13)$$

The model constants take the following default values [21–23]:

$$\begin{aligned} \alpha = 0.6, C_1 = 1.4, C_2 = 0.3, C_{\varepsilon 1} = 1.4, C_{\varepsilon 2} = 1.9, C_\eta = 70, C_\mu \\ = 0.22, C_L = 0.23, \sigma_T = 0.85, \sigma_k = 1, \sigma_\varepsilon = 1.3 \end{aligned} \quad (14)$$

The governing equations formulated above are discretized with the finite volume method and solved by commercial CFD software Ansys Fluent 13.0 [28]. The SIMPLE algorithm is employed for solving the pressure and velocity coupling. The discretization of pressure is based on the PRESTO! scheme, while the QUICK scheme is adopted for all the other variables. Non-uniform quadrilateral grids are employed, and the boundaries are inflated with nodes tightly clustered near the walls to ensure that the y^+ value for the first grid close to the walls is everywhere less than 1. A grid dependence test is conducted by comparing the results of a $\sim 30,000$ nodes grid with a $\sim 70,000$ nodes grid. It is shown that the difference between the two grids in the total mass flow rate and the

wall heat transfer rate results is less than 2%. The modeling results presented in this paper are all based on grids consisting of about 30,000 nodes.

Since there is no comparable experimental or numerical data in the literature for convection air flow in vented attic spaces, the present numerical model is validated through two benchmark problems of turbulent natural convection in enclosures.

The first benchmark problem is turbulent natural convection in an air filled square cavity of 0.75 m high and 0.75 m wide. The side walls of the cavity are differentially heated by keeping the left wall at 50 °C and the right wall at 10 °C, resulting in a Rayleigh number of 1.58×10^9 , while the cavity top and bottom are bounded by highly conducting walls. This problem has been studied both experimentally [29–31] and numerically [32–34], thus provides a good test to the present numerical model.

The modeling predictions shown in Figs. 2 and 3 are obtained by specifying all the boundary temperatures in accordance with the experimental measurements [31] and employing an 80×80 non-uniform grid. The predicted mean velocity and temperature fields shown in Fig. 2 are very similar to those measured from the experiments [29] and averaged from the large eddy simulation [32], while the predicted profiles of vertical velocity and temperature at the mid-height of the cavity agree very well with the experimental data [31], as shown in Fig. 3.

The second benchmark problem adopted to validate the present model is turbulent natural convection of air confined in an isosceles triangle-shaped attic, which was originally solved by Ridouane et al. [16]. The modeled domain has a width of 5.46 m and a height of 2.73 m. A uniform temperature of 273 K is applied to the roofs, while the ceiling is kept at 293 K. The streamlines and isotherms predicted by the present model are shown in Fig. 4. These results obtained based on the v2f model are in very good agreement with those given by Ridouane et al. [16], which were obtained based on a low-Reynolds number k - ε turbulence model.

3. Results and discussion

3.1. Sealed attic

Turbulent natural convection in a sealed attic is simulated first so that its results can be compared with the vented attic cases. The soffit vents are assumed to be 4 cm wide on each side, while the ridge vent is 8 cm wide. All the vents are sealed and assumed to be adiabatic, and the roof-top and ceiling-bottom temperatures are specified as shown in Fig. 1. As a result, the ambient air temperature has no influence on the modeling results. The ceiling insulation is assumed to be R-20 (simulating the thermal resistance of a layer of 15 cm thick glass fiber), resulting in a heat transfer coefficient of $h_c = 0.284 \text{ W/m}^2 \text{ K}$.

The predicted streamlines and isotherms for the sealed attic case are shown in Fig. 5(a and b), while the temperature variations along the ceiling and roof boundaries are shown by the solid lines in Fig. 6. Similar to the results shown in Fig. 4, the flow is asymmetric, although the geometry and boundary conditions are all symmetric about $x = 0$. The flow field is dominated by two convection cells, as shown by the streamlines. Air flow in the big cell is clockwise, while that in the small cell is counterclockwise. Both the ceiling and roof temperatures peak at around $x = -2$ m, where air in both cells is hottest and flows upward. The peak temperature along the ceiling is corresponding to a minimum heat flux, because the temperature difference across the ceiling thickness reaches the minimum there.

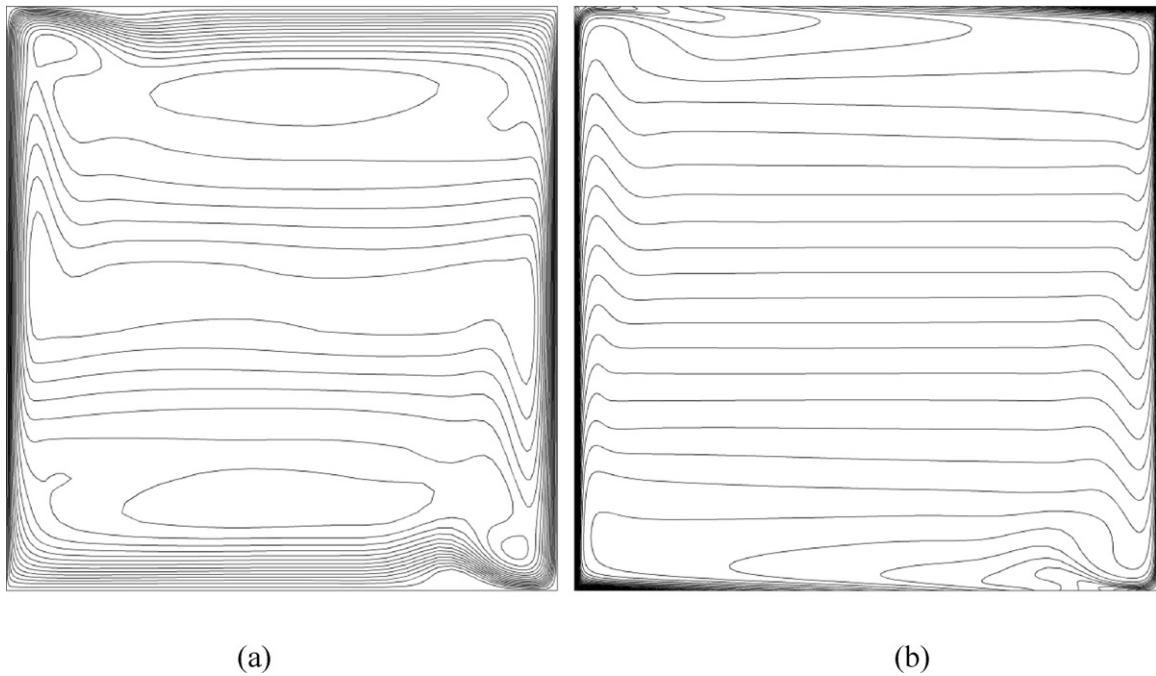


Fig. 2. Predicted streamlines (a) and isotherms (b) for the validation case of turbulent natural convection in square cavity.

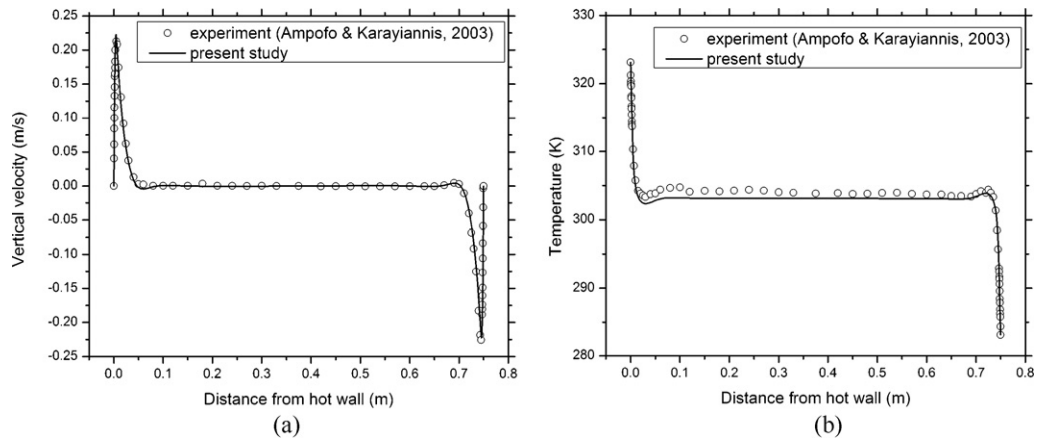


Fig. 3. Comparison of predicted vertical velocity (a) and temperature (b) at mid-height of the square cavity with experimental data [31].

However, the peak temperature along the roof reflects a maximum heat flux as the temperature difference across the roof thickness assumes the maximum value.

Fig. 6 shows that the roof temperature for the sealed attic is everywhere above the melting point of ice, indicating a favorable condition for ice dam formation. A study by Tobiasson et al.

[35] observed that severe icing problems tended to occur when the outside temperature was below 22 °F (267.5 K) and the attic air temperature was above freezing. An effective approach to avoid problematic icings is to provide appropriate attic ventilation together with sufficient ceiling insulation to maintain an attic temperature below freezing when outside is cold.

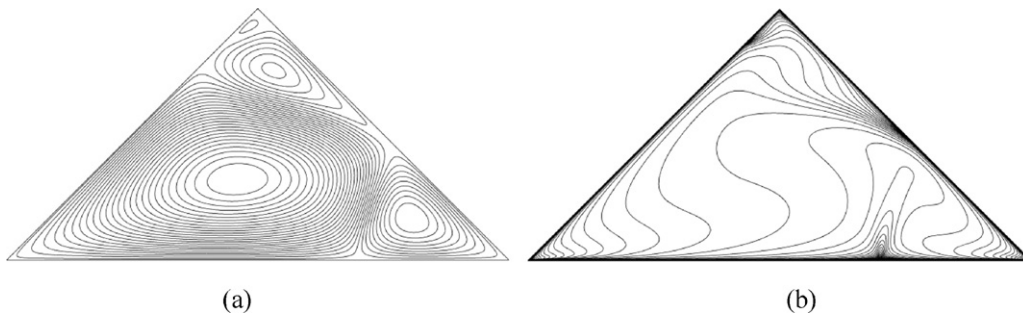


Fig. 4. Predicted streamlines (a) and isotherms (b) for the validation case of turbulent natural convection in triangular cavity.

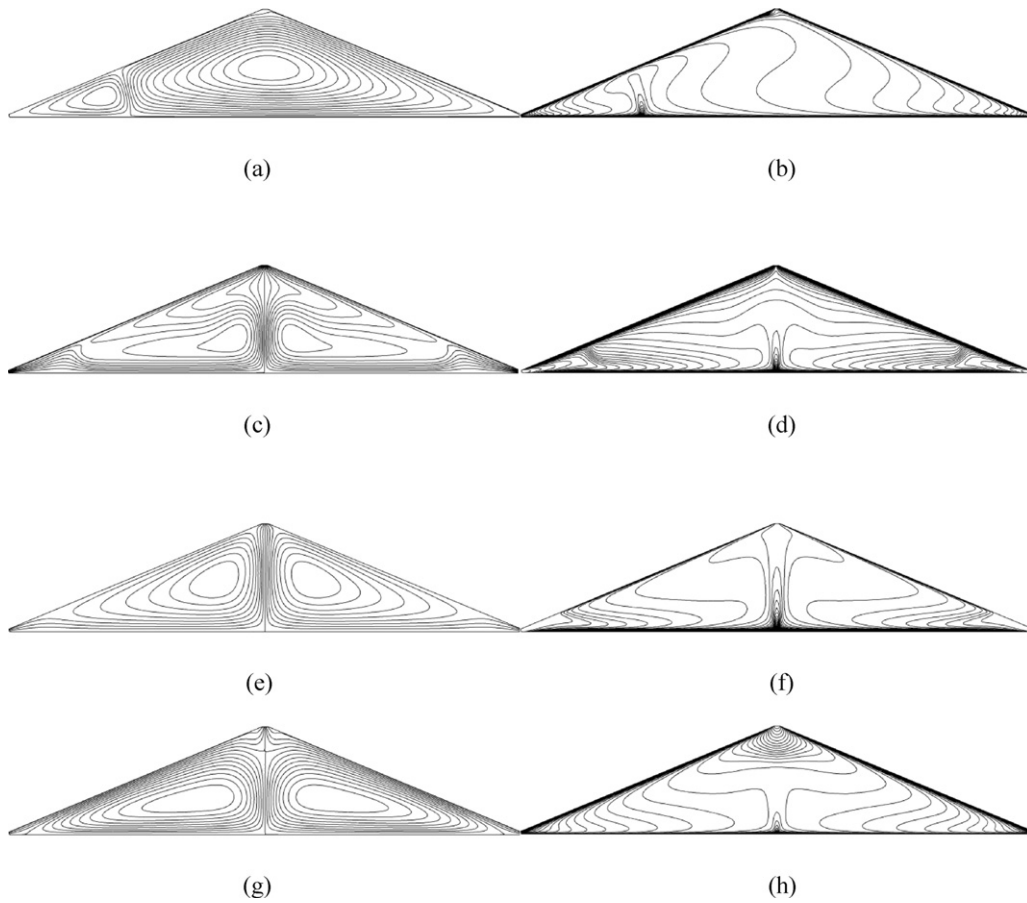


Fig. 5. Predicted streamlines (left) and isotherms (right) for the cases of sealed attic (a and b), $T_{in} = 263\text{ K}$ (c and d), $T_{in} = 273\text{ K}$ (e and f), and $T_{in} = 283\text{ K}$ (g and h) with 4 cm soffit vents and R-20 ceiling insulation.

3.2. Effects of ambient air temperature

In contrast to the sealed attic case, the air flow and heat transfer inside a vented attic will depend on the ambient air temperature, because the outside air enters the attic at the ambient temperature. Under winter weather conditions, the ambient air temperature may be below, equal to, or above the roof temperature. These three situations are corresponding to the three cases presented below. In the modeling of these cases, a 4 cm soffit vent on each side and an 8 cm ridge vent, together with an R-20 ceiling insulation, are assumed.

In the first case, the outside air enters the soffit vents at 263 K, i.e., 10 K below the roof-top temperature. The predicted streamlines and isotherms are shown in Fig. 5(c and d), while the temperature variations along the ceiling and roof boundaries are shown by the dashed lines in Fig. 6. Both the velocity and temperature fields are symmetric about $x = 0$, which is clearly different from the asymmetric pattern for the sealed attic case. As a matter of fact, for all the vented attic cases investigated in this study, symmetric solutions are obtained. It seems that the ventilating air flow stabilizes the symmetric solution, which is unstable in the sealed attic case.

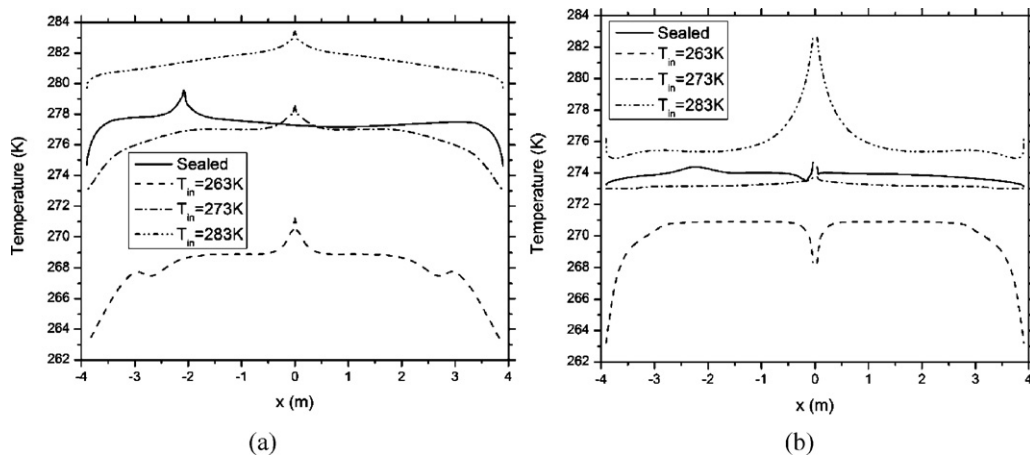


Fig. 6. Predicted temperatures at the ceiling (a) and roof (b) boundaries for the cases of sealed attic, $T_{in} = 263\text{ K}$, $T_{in} = 273\text{ K}$, and $T_{in} = 283\text{ K}$ with 4 cm soffit vents and R-20 ceiling insulation.

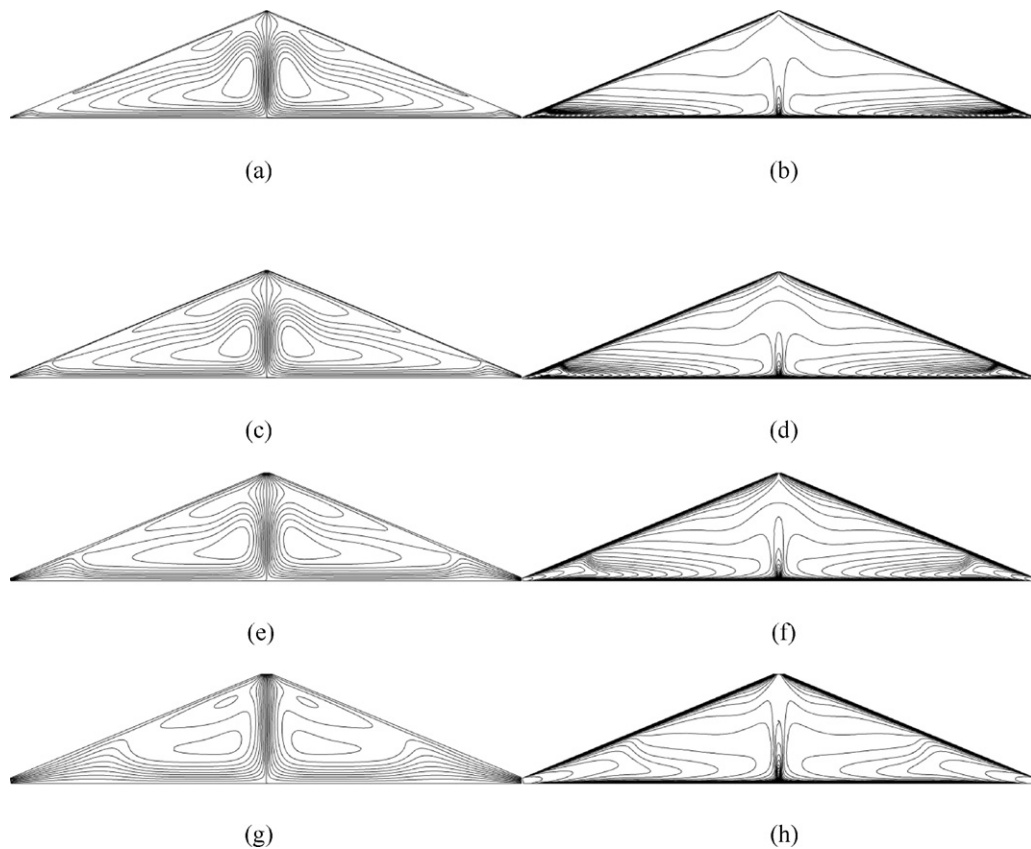


Fig. 7. Predicted streamlines (left) and isotherms (right) for the cases of 1 cm (a and b), 2 cm (c and d), 4 cm (e and f), and 8 cm (g and h) soffit vents with $T_{in} = 267$ K and R-20 ceiling insulation.

For the $T_{in} = 263$ K case, since the entering air is colder than both the roof and ceiling, it is first heated from both sides near the soffit vents, then travels along the ceiling for further heating, and finally rises at the attic center and eventually leaves the attic through the ridge vent (Fig. 5). The temperature distribution in the top half of the height is vertically stratified, while that in the bottom half is controlled by the two symmetric recirculating cells. The ceiling temperature peaks at the center, while the roof temperature reaches a local minimum near the ridge. Fig. 6 shows that the temperature is below 271 K along the entire roof width, indicating a cold roof that will not allow ice dam to form.

In the second case of vented attic, the inlet air is assumed to have a temperature of 273 K, equal to the roof temperature. The model predictions are shown in Fig. 5(e and f) and by the

dash-dot lines in Fig. 6. The outside air, entering from the soffit vents, is first heated along the ceiling, then forms a rising vertical plume around the attic center line, $x = 0$. At each side of the plume, there is a recirculating convection cell. The temperature distribution is dominated by the plume and convection cells, and no vertical stratification is observed in the temperature field. Both the ceiling and roof temperatures peak at $x = 0$.

In the third case, the inlet air temperature is assumed to be 283 K. The results are presented in Fig. 5(g and h) and by the dash-dot-dot lines in Fig. 6. Different from both the $T_{in} = 263$ K and $T_{in} = 273$ K cases, air flow in the $T_{in} = 283$ K case is downward, i.e., entering from the ridge vent and leaving through the soffit vents. The reason for the sinking air flow is that it is actually cooled instead of heated in the attic space. Although the inlet air could be cooled

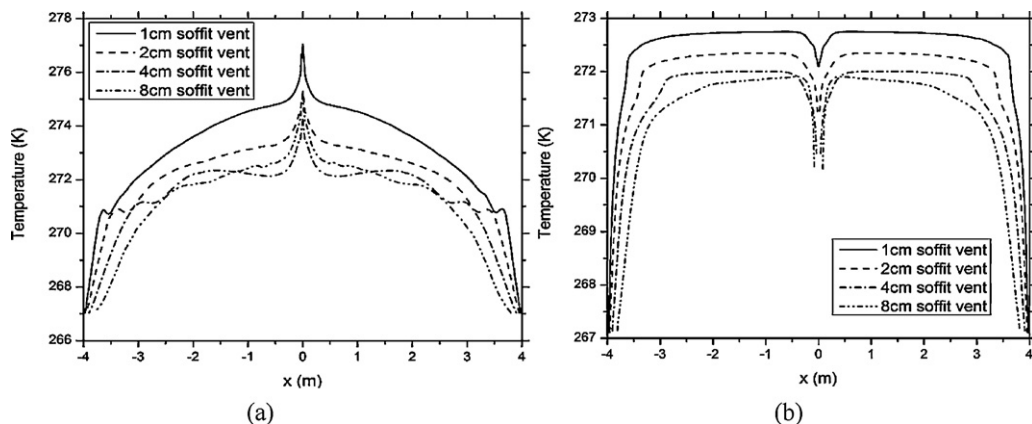


Fig. 8. Predicted temperatures at the ceiling (a) and roof (b) boundaries for the cases with different vent sizes ($T_{in} = 267$ K and R-20 ceiling insulation).

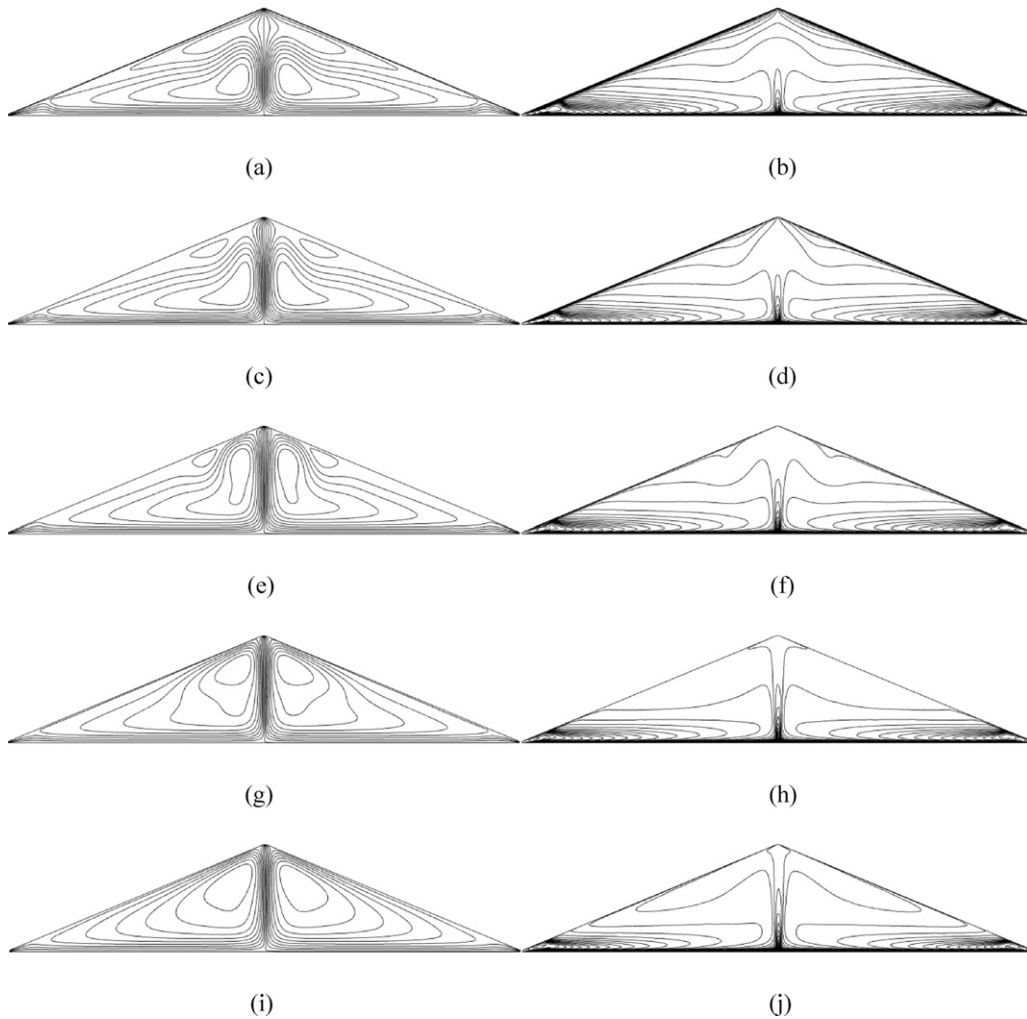


Fig. 9. Predicted streamlines (left) and isotherms (right) for different ceiling insulation cases of R-20 (a and b), R-10 (c and d), R-5 (e and f), R-2.5 (g and h), and R-1.2 (i and j) with $T_{in} = 267$ K and 2 cm soffit vents.

by the roofs and heated by the ceiling, the much better insulation across the ceiling than that across the roofs makes the cooling effect dominate. As a result, the outside air, entering from the ridge vent, mainly travels along the roofs. Below the roof free stream sit two recirculating convection cells. The temperature field is stratified only at the top portion above the convection cells. Fig. 6 shows the

roof temperature is well above the ice point, but it is not relevant to ice dam formation, because the outside temperature is too high to allow ice dams to form.

The total heat transfer rates across the ceiling and roof boundaries as well as the air flow rates for the three cases with different inlet air temperatures are compared in Table 1, together with the

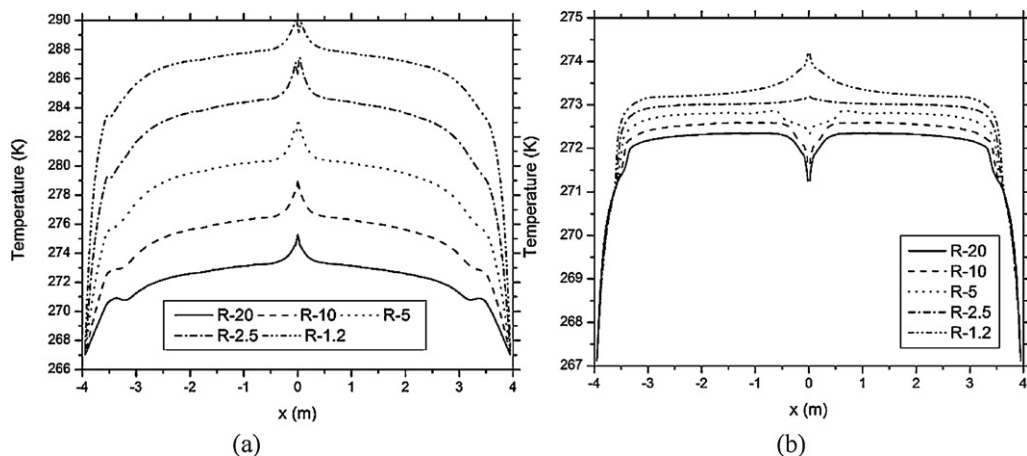


Fig. 10. Predicted temperatures at the ceiling (a) and roof (b) boundaries for the cases with different ceiling insulation levels ($T_{in} = 267$ K and 2 cm soffit vents).

Table 1

Predicted total heat transfer through the ceiling and roof boundaries and air flow rate across the attic for the cases of sealed attic, $T_{in} = 263$ K, $T_{in} = 273$ K, and $T_{in} = 283$ K with 4 cm soffit vents and R-20 ceiling insulation.

Inlet air temperature (K)	Heat gain from ceiling (W/m)	Heat gain from roof (W/m)	Upward mass flow rate (kg/s m)
sealed	34.4	-34.4	0
263	55.4	109.2	0.0445
273	36.6	-7.78	0.0305
283	25.6	-117.0	-0.0176

sealed attic case. The heat gain from the ceiling reflects the energy consumption of the attic space in the heating load of the building. Table 1 shows that a vented attic consumes more energy in cold days and saves heating energy in warm days, as compared to a sealed attic. It is also observed from Table 1 that the air flow rate in cold days is higher than that in warm days. Considering that the moisture entering an attic from the conditioned space of a building is more likely to condensate in cold days, the higher ventilation air flow rate offers a natural regulation to meet the need of venting moisture out of the building.

3.3. Effects of vent size

In this section, modeling results of attic ventilation with different vent sizes will be presented. Four sizes of soffit vent, viz., 1 cm, 2 cm, 4 cm, and 8 cm, are analyzed. For all the four cases, the size of ridge vent is kept as twice of the soffit vent to satisfy the balanced ventilation condition, and the ceiling insulation is kept as R-20. The inlet air temperature is set to 267 K, in order to investigate the possibility of ice dam formation. Based on field observations, Tobiasson et al. [35] concluded that problematic icings developed very slowly, if at all, when the outside temperature was above 267.5 K. The choice of outside temperature of 267 K is corresponding to a condition that is most favorable for ice dam development.

The predicted streamlines and isotherms are shown in Fig. 7, while the ceiling and roof temperatures are shown in Fig. 8. The flow and temperature fields for the different vent sizes exhibit similar pattern, although quantitative variations exist, as evident in Fig. 8 and Table 2. In general, both the ceiling and roof temperatures decrease with increasing vent size, indicating larger vents bring stronger cooling effects. Fig. 8 shows that the roof temperature is below 273 K for all the cases, indicating a cold roof is maintained that prevents ice dam to form.

A comparison of total heat transfer through the roofs and ceiling as well as air flow rate across the attic for different vent sizes is provided in Table 2. The table shows that the air flow rate increases with the vent size but not in a linear way. For example, the increase of the soffit vent from 1 cm to 2 cm increases the air flow rate by 71%, while the increase from 4 cm to 8 cm only increases the air flow rate by 51%. It is interesting to observe that the heat gain from the ceiling is barely influenced by the vent size change. This may be explained by that the higher mass flow rate associated with a larger vent gains more heat from the roofs, as evident from Table 2.

Table 2

Predicted total heat transfer through the ceiling and roof boundaries and air flow rate across the attic for the cases with different vent sizes ($T_{in} = 267$ K and R-20 ceiling insulation).

Soffit vent size (cm)	Ventilation rate	Heat gain from ceiling (W/m)	Heat gain from roof (W/m)	Upward mass flow rate (kg/s m)
1	1:200	44.8	21.5	0.0137
2	1:100	46.8	40.8	0.0238
4	1:50	47.7	56.8	0.0409
8	1:25	46.7	63.8	0.0675

Table 3

Predicted total heat transfer through the ceiling and roof boundaries and air flow rate across the attic for the cases with different ceiling insulation levels ($T_{in} = 267$ K and 2 cm soffit vents).

Ceiling insulation	Heat transfer coefficient (W/m ² K)	Heat gain from ceiling (W/m)	Heat gain from roof (W/m)	Upward mass flow rate (kg/s m)
R-20	0.284	46.8	40.8	0.0238
R-10	0.568	81.2	32.5	0.0264
R-5	1.136	130.4	23.4	0.0292
R-2.5	2.272	188.6	13.7	0.0320
R-1.2	4.733	257.8	2.04	0.0347

3.4. Effects of ceiling insulation

The effects of ceiling insulation on heating load and ice dam formation are investigated through five cases with ceiling insulation of R-20, R-10, R-5, R-2.5, and R-1.2, respectively. The attic is assumed to have a ventilation system consisting of a 2 cm soffit vent on each side and a 4 cm ridge vent, while the inlet air temperature is kept as 267 K.

As shown in Fig. 9, the flow and temperature fields vary significantly with the ceiling insulation change. It can be observed that two big convection cells increase with the decrease of the ceiling thermal resistance, and eventually dominate the temperature distribution.

Fig. 10 shows that both the ceiling and roof temperatures increase when ceiling thermal resistance decreases. Also shown in Fig. 10 is that the roof temperatures in the R-2.5 and R-1.2 cases are higher than 273 K, favoring ice dam formation. This result provides quantitative evidence to support the qualitative common believing that a combination of appropriate attic ventilation and sufficient ceiling insulation is required to effectively prevent ice dam formation.

In Table 3, total heat transfer through the roofs and ceiling as well as air flow rate across the attic are compared for different ceiling insulation levels. Along with the decrease of ceiling thermal resistance, both heat gain from the ceiling and air flow rate increase, while the heat gain from roofs decreases. Therefore, improving the ceiling insulation not only helps preventing ice dams but also provides an effective way to reduce heating energy consumption.

4. Conclusions

Buoyancy-driven turbulent ventilation in attic space under a gable roof under winter conditions is simulated in terms of a CFD model. The findings from the numerical results are summarized as follows:

- (1) For all the investigated cases, air flow in vented attics tends to be symmetric, in contrast to the asymmetric pattern found for air flow in sealed attics.
- (2) As compared to a sealed attic, a vented attic consumes more energy in cold days and saves heating energy in warm days.
- (3) Ventilation air flow rate is higher in cold days than in warm days, providing a natural regulation to satisfy the varying demand of venting moisture out of a building.
- (4) Increasing vent size results in higher ventilation air flow rate but barely affects the attic heating load.
- (5) Both sufficient ventilation and ceiling insulation are needed to effectively prevent ice dam formation and make a building energy-efficient.

It should be noted that the above-mentioned conclusions are subject to the limitations of the model assumptions adopted in this study. This research can be furthered in the following aspects:

- (1) Investigating wind effects. The air flows presented in this study are purely driven by buoyancy. Such buoyancy-driven cases are corresponding to a worst-case scenario, because real attic ventilation is generally enhanced by winds.
- (2) Including moisture transfer. The contribution of the latent heat associated with moisture transfer may be significant for the energy performance of attics in humid climates, especially in summer times.
- (3) Simulating attic ventilation under summer conditions. The results presented in this paper apply to winter conditions only, but the methodology employed here can be extended to investigate attic ventilation under summer conditions or year-round performance as well.

Acknowledgment

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Appendix C: Conference Papers

Creating 3D web-based game environment using BIM models for virtual on-site visiting of building HVAC systems

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Abstract: A web-based 3D game project was presented in this paper to demonstrate the process of using building information modeling (BIM) to create an interactive 3D on-line ‘Green’ training environment. The system architecture, the implementation process and major components of this virtual training environment were discussed. Existing studies on BIM-based collaborations mainly focused on local-file-sharing approach using proprietary applications. Limited research focused on using BIM as an online gaming platform to create a web browser-based interactive 3D virtual environment for collaboration, learning and/or training. The gap was partially caused by the lack of understanding how to implement a BIM-based game in web browser environment. In this paper, the authors provided an implementation example using a hospital BIM model to create an interactive web-based 3D BIM game environment to allow users to visualize and interact with the BIM components using regular web browsers. The intention of this project is to create a proprietary-independent training environment to conduct energy re-commissioning trainings for hospital facility management staff. This virtual BIM environment can potentially be customized for engineering student learning and project collaborations as well. The conclusion was that current BIM and game technology are mature enough to allow us to create serious web-based interactive learning/training virtual environment. The successful integration of BIM and web browsers paved the way for many learning and training applications, which need built-environment as context.

Key words: BIM; 3D, web-based, interactive, virtual, training, hospital, HVAC, implementation, energy retrofitting

INTRODUCTION

This research is part of a US Department of Energy sponsored veteran energy retrofitting training project, which aims to develop online training curriculum of energy retrofitting of hospital and/or commercial buildings for veterans to work as ‘Green’ building professionals. One of the challenges in developing this online training curriculum is how to conduct necessary on-site trainings to demonstrate the basic working principles of different complex HVAC systems, under constraints of limited training time and budget.

To answer the challenge the PIs investigated the potentials of using three-dimensional (3D) virtual site visit to substitute for actual site visits. BIM models of HVAC systems were used in regular web browsers to create a 3D game environment for virtual site visit. This primary objective of this research is to develop a web-based 3D virtual HVAC ‘on-site’ training environment to provide realistic 3D learning context of actual building and HVAC systems. The 3D BIM models HVAC systems used in this paper were created based on an actual VA hospital.

Since the targeted users are often located in geographically dispersed locations across the globe, and they may not be able to access the learning materials at the same time, web-

based virtual self-learning appears to be a feasible choice. In addition, web-based applications are less likely to have issues with hardware devices and issues with updating contents compared to standalone game applications.

Web-based 3D interactive game environments have been used in many areas including science, engineering and medical training (Cook et al. 2011; EI Rhalibi 2009 et al.; Hendaoui et al. 2008). Its value in learning and training was widely recognized (Cook et al. 2011; Gonzalez 2008). Their application in architecture, engineering and construction (AEC) area have gained increased attentions from both industry and academia alike (Kumar et al. 2011; Guo et al. 2011; Lin et al. 2011), particularly due to the increased presence of 3D design technology, such as building information modeling (BIM) (Eastman et al. 2011; Shen and Issa 2010) and/or Google SketchUp (Choo & Phan 2010) in design, construction and research communities.

A major challenge in creating a realistic built environment in 3D game engine is to create large-scale, detailed, and realistic building models. Two technical issues were responsible for the difficulty: 1) most 3D game engine is not designed for creating complex detailed building designs. So it is difficult and time consuming, if possible, to create realistic building models using game engines' own design functions. 2) Data interoperability between design software and game engine was a significant issue previously (Shen et al. 2007). Few game engines were able to import 3D design files seamlessly into the web-based game environment while maintaining the desired detailed information about building properties.

Recent progress in data interoperability in AEC modeling software as well as the new development in Web3D technology has created opportunities to use existing 3D design, especially BIM models, to create complex realistic built environment for immersive learning or virtual 'on-site' training.

In this paper the authors presented an implemented case to demonstrate the feasibility and potential of creating web-based interactive 3D virtual built environment using BIM models. The models included a hospital's floor layout and the corresponding HVAC systems. The intended training topics included how to fix and enhance the performance of hospitals' HVAC systems. Two important advantages of the virtual 'on-site' training environment are 1) it allows trainees to access, observe, and manipulate the different types of hospital HVAC systems without affecting the actual hospitals operations; and 2) trainees do not need to travel to the actual hospitals sites to see how the actual HVAC systems works. Three specific objectives were considered in this project.

1. Identify appropriate architecture, procedures, components, platforms, and data for creating the web-based on-site virtual training environment.
2. Identify appropriate game engine, which is able to take necessary BIM information in the game environment.
3. Develop virtual 3D immersive training scenarios and visualization of the HVAC systems. Users are expected to be able to observe realistic animations of airflows of supply, return and exhausting in normal and abnormal conditions.

RELATED WORKS

Web-based immersive learning environment (Floryan and Woolf 2011; Cai et al. 2008) has gained increased attention in recent years due to the significant advancement in information technology and cyber-infrastructure. For example, Simpson et al. (2007) have developed two cyber-infrastructure-based repositories to support engineering design among three universities; and Moon et al. (2008) have developed a cyber-learning system to support aerospace engineering. Study (Dede 2009) indicated that immersion in a 3D interactive

environment can contribute to effective learning by allowing multiple perspectives, situated learning, and transfer.

2nd Life as a major player in 3D virtual game environment gained significant interests from educational community due to its potential of creating an immersive virtual learning environment (Mallan et al. 2010; Warburton 2009). However, one of its major drawbacks is the difficulty to create realistic built environments using its own primitive-shape library, and it has significant issues in its interoperability with BIM models (Ku 2011). Due to this limitation, its applications in ACE community were limited.

BIM models are able to provide realistic and detailed 3-D virtual environments with graphical and non-graphical data that represent key properties of building system. BIM has gained significant market in AEC industry in recent years. Its applications originally focus mainly on design and construction (Eastman et al. 2011; Zhang and Hu 2011, Shen and Issa 2010). More recently, the applications started to extend into buildings' lifecycle management (Wang and Shen 2011), such as as-built documentation (Tang et al. 2010) and facility management (Vanlande et al. 2008).

Despite the rapid development in BIM's applications, using BIM model to create 3D interactive computer game is still relatively new. Existing BIM-based computer game research were mostly focused on stand-alone game application. Kumar et al. (2011) developed BIM-Unity3D based game application for evaluating healthcare facility designs. Lin et al. (2011) developed a single-player game for construction safety training. These two projects were not web-based, which means that a standalone game application is required to be installed on user's computer.

Few projects and literature on web browser-based 3D interactive BIM game environment are found to the authors' best knowledge through extensive literature reviews. However, since web browsers are standard components of almost any PCs and mobile devices, developing web-based 3D interactive game environment will has significant value and can provide general public broader accesses to, and sharing of, virtual learning environment.

THIS PROJECT

The selection of game engine

Game engine selection is the key in achieving the goal and objectives set for this project. Several criteria were set for candidate game engines considering the open accessible nature of the developed application. The criteria included capacities of 3D, cross platform, supporting importing BIM exporting file format (especially FBX file format), supporting different operating systems, open source, and affordability. After extended screening process, Unity3D game engine (Unity3D 2011) was identified as the game engine used to carry out the tasks. Unity3D can take BIM models through FBX file format to import geometric, and texture, and other material properties from Autodesk Revit BIM models. And the developed games can be deployed in Windows, Mac, and iOS and Android systems.

The framework of the system

Figure 1 shows the architecture of the proposed system. On the server side, we deploy the source files including 3D model data and offline game deployments to support the Web platform interface. On the client side, the proposed the 3D interactive environment can be acceptable by multi-type browsers via a Web player plug-in. The interactions and object behaviors in user-model are defined using the scripting language functions embedded in both webpage HTML files and 3D game deployment. In game development, the objects were imported in 3D environment as "asset" from BIM models through FBX file format.

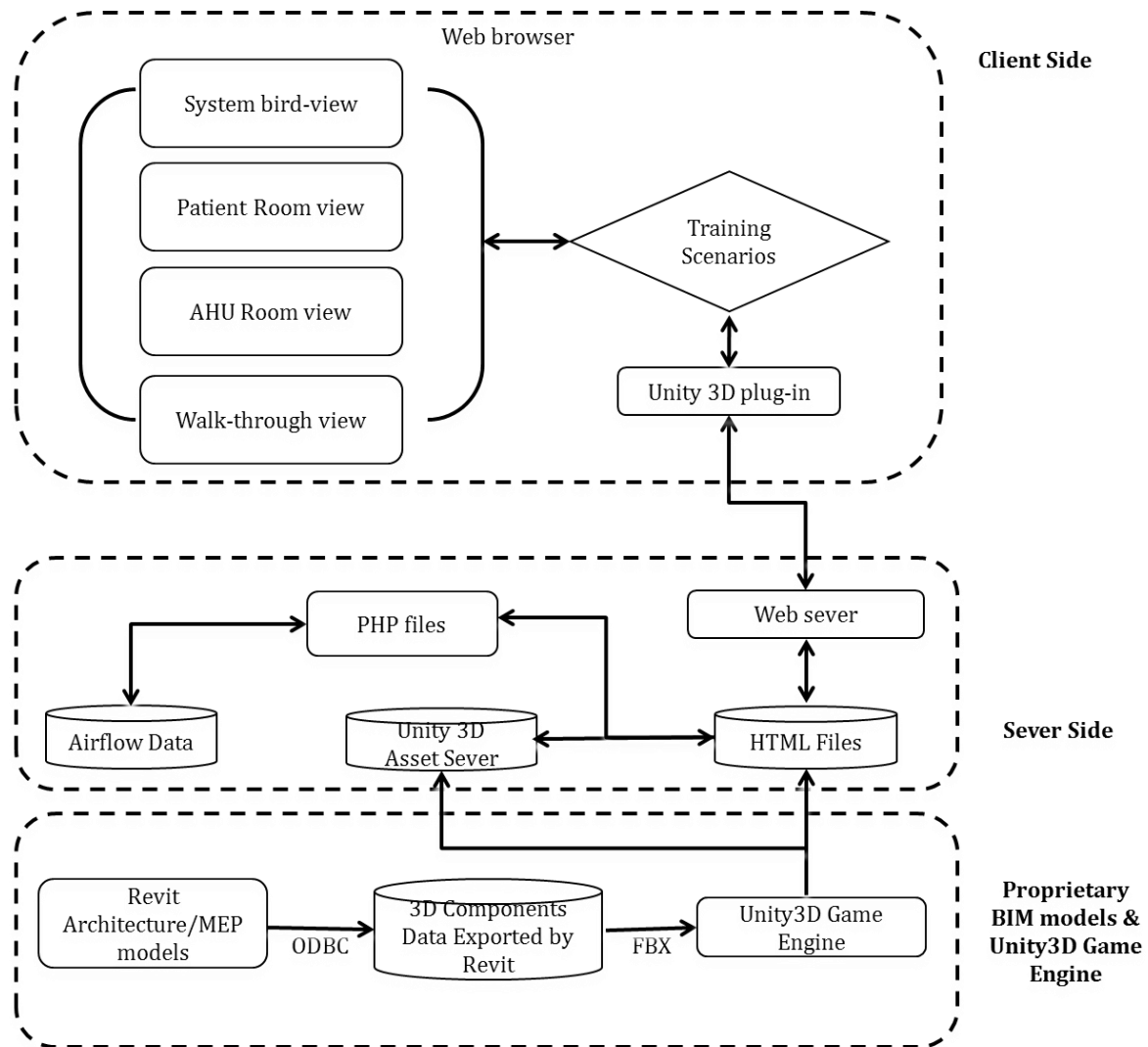


Figure 1. The architecture of the implemented game environment

Other than entertainment purpose, games developed for education, training, research exploration purposes are often called “serious game”. So one notable component in this developed serious game is the airflow database, which was the actual HVAC data measured from the on-site inspections. The data was pulled out when users click the corresponding objects while playing the game. The data was also used to control the effects of the particle simulations, which animate the airflows of fresh air, return air, and exhaust air in the HVAC systems.

Figure 2 below illustrates the web-based interaction design using three-layer of abstractions: user interface exported by game engine, middle layer functions in HTML files and backend databases. Such three-level framework enabled each simulation in the frontend connected to the database through script functions in HTML files. Web based programming provides solutions for database access control and also guarantees the security of the database, and reusability of the scripts. Due to the reusability of the script functions, new scenarios in hospital operation or a brand new training environment can be easily loaded on the same database side without substantial amendments.

When a user activates a scenario in Figure 1, the user interface will make a function call (JavaScript functions) to HTML file on client side. In the HTML file, JavaScript and

PHP functions transfer variable values to each other. On the server side, PHP files will select corresponding data from database and return them to the target functions in HTML file. As a result, the user would see the corresponding data on the webpage.

In this developed prototype, multi-player functions were not implemented. Future work can extend multiplayer functions into the same simulation environment.

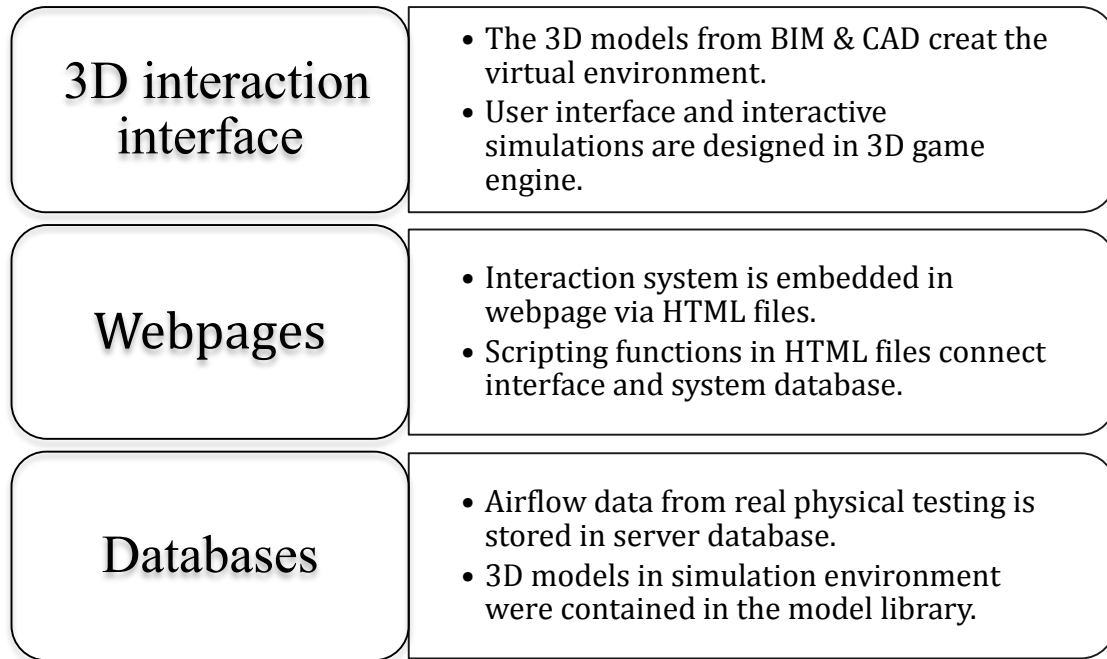


Figure 2 the web-based three-layer interaction design

The use of multiple-camera views to control training contents

In games for entertaining purpose, unpredictable encounters and surprises were often used to attract players' attention. In the proposed system, the authors felt the need of reducing surprises and unpredictable user behaviors in order to make players focus on the training scenarios. To achieve this goal the authors designed a series of controlled camera views to represent training scenarios. Game players will have particular position view to watch the specified events/scenarios by clicking the different location buttons. This design effectively eliminated times wasted on navigating through buildings to find interested locations in the building. In serious games we believe this is a good way to control the training contents intended to deliver to the players. Figure 3 illustrated the specified camera views labeled in Figure 1.

For example, cameras in 3b, 3c and 3d, were set with constrained views, which can only be used to look around in that particular room. In this way unnecessary walk-through and/or unintentional moves will be banned to let player just focus on the different flow patterns.

Position fixed camera views can also be used to help players to navigate through complex buildings. Figure 3d showed a walk-through scenario in a complex building using orthographic camera view as a navigation map provided in Unity3D. The map was overlaid on top of the 3D walk-through view on the lower-right corner. The red arrow on the map showed the player's actual location and facing direction.

So far, to the best of our knowledge, we have not seen literature on discussing the use camera control to help game players to focus on the intended contents. Further research might be needed in this area.

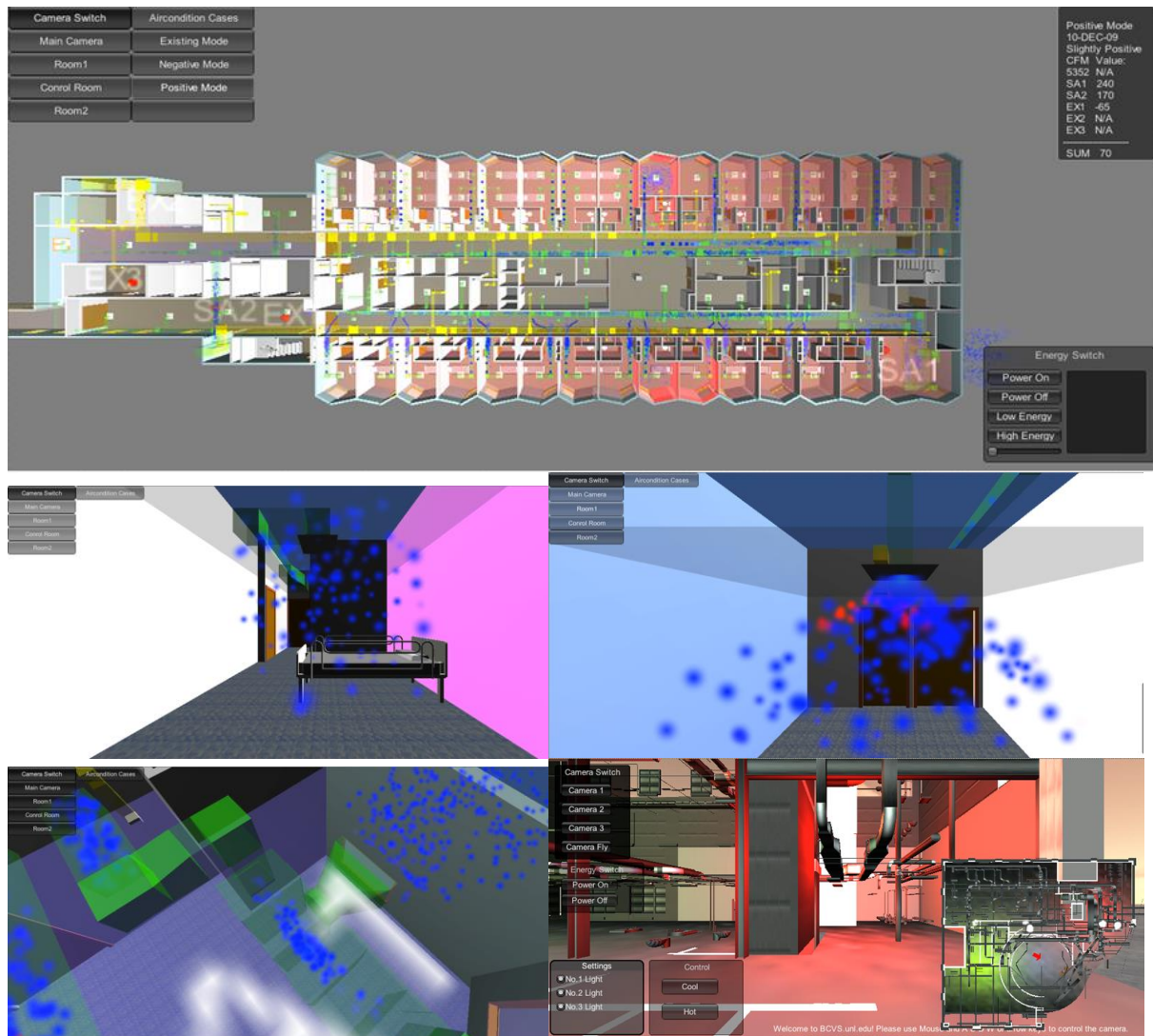


Figure 3. The use of camera views to direct players to the intended learning contents 3a (top)-floor view; 3b (middle)-patient rooms; 3c (lower-left) AHU room; 3d (lower-right)-walk through view with a navigation map

Correlate particle effects with airflow data

In this project, the actual airflow data was taken from six sampling points in the HVAC system at different building locations, which were labeled on the floor views of Fig 3a. Particle effects were used to animate the airflow patterns, which is normally invisible when visiting actual building systems.

Unity 3D provide a well performance particle system which are primarily used for effects such as smoke, fire, water droplets, or leaves. In HVAC system, we design the shape of it to be airflow objects in supply and exhaust duct. To distinguish two parts, we set the supply airflow blue color and red color for exhaust. In different scenario simulations, the energy and emission of the particle system will be also related to the value from airflow database.

The materials and render of the hospital building are also very important. For easy monitoring, a transparent ductwork and ceiling group are needed. We set the alpha value of

the objects color to be under 0.35. From the patient Isolation room in Fig 3b and AHU room in Fig 3c. We can see that the airflow going through the duct and spreading in isolation room is well simulated by the particle system.

In order to make the animated airflow match the field-measured data, a pseudo correlation was used to correlate particle densities to the actual airflow values. This correlation was purely for illustration purpose, and did not have any computational fluid dynamics (CFD) bases. However, actual CFD simulations could be added as video clips in this game environment in future development.

Example training scenarios using this 3D game environment

One training case is to show game players the status of room pressures, which are critical for some special rooms in hospital. For example, patient insolation rooms need to keep certain level of negative pressure in order to prevent spread out of contagious airborne germs or particles. Different color codes were assigned to areas showing positive, negative, and neutral air-pressures, so users can watch how room pressure changed based on the sampled measurements. For example, Table 1 showed significant level of negative pressure (in-balanced) at Day 1, and the situation was addressed by increasing fan frequency at SA1, and decreasing fan frequency at EX1. The result of the changes is a balanced negative pressure at Day 2.

Table 1. Example data sets used in creating training scenarios

Sampling points	Parameters	Day 1 data	Day 2 data	Unit
SA1	Ward supply air	4536	5760	CFM
SA2	Lobby supply air	2141	2147	CFM
EX1	South exhaust air	-3297	-2527	CFM
EX2	North exhaust air	-4512	-4579	CFM
EX3	Lobby exhaust air	-1256	-1289	CFM
Total		-2388	-488	CFM

Note: CFM represents cubic foot per minute (CFM), which is used to measure the rate of air exchange.

In other cases, instructors can create scenarios with single or multiple faulty symptoms that are visible to the users in the 3D model, and then challenge the users by asking them to come up with corrective action. This type of problem-based case study can be very powerful when combined with 3D virtual model, which simulating the actual on-site scenarios.

RESULTS

By selecting the appropriate game engine and BIM authoring tools, we were able to create a web-based immersive 3D BIM learning environment for HVAC system on-site training. The smooth transition from BIM models to 3D game models in this project suggested that the previous interoperability issue between BIM and game applications has been improved significantly. Moreover, we found a way to add a knowledge-based module (the air-flow database) to the game environment so the virtual game environment can be used to conduct topic-specific HVAC trainings. The successful implementation of the external-database module paved the way for more topic-specific trainings in same BIM environment. The implemented prototype provided a proof of concept of using BIM for creating serious 3D virtual game environment, which have great potentials in AEC industry. Since we have not started the testing phase of the project, results from user side are not included in this paper.

CONCLUSIONS AND FUTURE RESEARCH

In this paper, we presented the goal/objectives, the research procedure, and the findings as the result of the implementations, of a research project using BIM models to create a web-based 3D virtual training platform to provide a capacity of virtual on-site visiting to actual HVAC systems. The intended users can manipulate and interact with virtual 3D HVAC systems in the realistic built-environment context. The authors anticipate improved learning outcomes of commercial HVAC systems compared to static learning environment, in which texts, numbers, and pictures are the only learning media.

The experimented 3-D Web technology offered a potential alternate solution to conducting large-scale Green building training using existing information technology, especially 3D graphical technology, and cyber infrastructure. The success of the project can potentially lead to significant improvement in training and learning of Green technology and knowledge in engineering area.

The preliminary findings and results of this project suggested that previous barriers of interoperability among different data structures have been reduced significantly. In the case of this project, we are able to import a significant portion of data in BIM models into the Unity3D game engine. The improvement in the data interoperability may soon to unleash the potentials to create serious realistic 3D virtual environment using BIM models for numerous applications included, not limited to, learning and training.

In our case, the developed virtual ‘on-site’ platform is able to provide almost unlimited ‘on-site’ training resources, which cannot be achieved using physical resources. Another advantage of this virtual platform is its ability allowing trainees to mess-up things, which is very unlikely in a physical built facility. Since the implemented system is based on thin-client web browser, high-power desktop or workstation is not necessary to have a satisfactory performance. The implemented thin-client feature allows average laptops to have decent performance when playing with the game.

The authors would like to point out that the research project described in this paper is a proof-of-concept in nature, despite the positive implementation results. Further, and larger scale implementation of BIM based 3D virtual game environment projects are needed to understand the scalability issue of this implementation framework. Another limitation of this research is the lack of quantitative evaluations of its effectiveness from users’ perspectives. Future extension of the research will address the limitations.

ACKNOWLEDGEMENT

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ACSEE 2013 Conference, June 6-9, Osaka, Japan

Investigating potentials of self-cooling cavity wall system in reducing buildings' summer peak cooling load

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The University of Nebraska – Lincoln, June 8, 2013

Background

Regional energy use and growth rate

	kWh/capita			Population (million)			Energy use (1,000 TWh)		
	1990	2008	Growth	1990	2008	Growth	1990	2008	Growth
USA	89,021	87,216	-2%	250	305	22%	22.3	26.6	20%
EU-27	40,240	40,821	1%	473	499	5%	19.0	20.4	7%
Middle East	19,422	34,774	79%	132	199	51%	2.6	6.9	170%
China	8,839	18,608	111%	1,141	1,333	17%	10.1	24.8	146%
Latin America	11,281	14,421	28%	355	462	30%	4.0	6.7	66%
Africa	7,094	7,792	10%	634	984	55%	4.5	7.7	70%
India	4,419	6,280	42%	850	1,140	34%	3.8	7.2	91%
Others*	25,217	23,871	nd	1,430	1,766	23%	36.1	42.2	17%
The World	19,422	21,283	10%	5,265	6,688	27%	102.3	142.3	39%

Background (cont.)

- Aging infrastructure (water, energy, transportation, ...)
- Budget/debt issues (\$16.8 trillion, \$56,000/capita)
- Population growth (440 million by 2050 projected, from 300 million in 2007)
- Large building inventory

Cavity Wall Systems

Commercial Cavity Walls

Residential Cavity Walls

Figure 1
Brick Veneer/Wood Stud Wall

(a) CMU Foundation/Wood Floor

Related Studies

1. Ventilated façades - added wall layer outside the existing facade (Altan et al 2008)
2. Solar chimney, which utilize solar-irradiance induced ventilation to improve indoor ventilation (Sakonidou et al. 2008; Zamora & Kaiser 2009)
3. Ventilated cavity wall (Ciampi et al. 2003; Griffith 2006) and ventilated roofs or attics (Susanti et al. 2008, Wang et al. 2012).

All these studies more or less confirmed the effects of natural ventilation of building envelopes on energy savings.

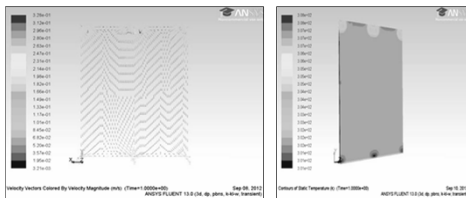
However, little comprehensive parametric study of ventilated wall solutions was found on the existing cavity-wall inventory.

Objectives

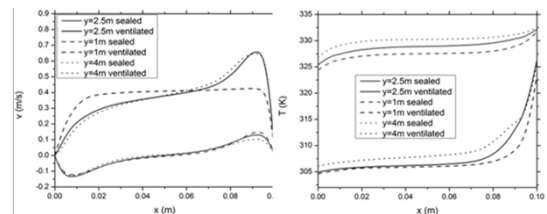
1. To understand the potential of reducing heat induction through walls using buoyance-driven ventilation in wall cavities
2. To provide scientific guidance for new energy efficient building design and energy retrofit of existing buildings

Approach

- Major part of the study was conducted through numerical simulations with literature validations.



Preliminary Results



Wall height (m)	Cavity thickness (cm)	Mass flow rate (kg/m s)	Cooling load (W/m)	R-value of the air channel
5	5	0.02906	15.36	47.44
7.5	5	0.03689	24.67	42.80
10	5	0.04334	34.88	39.06

Expected Outcomes

- Detailed design and retrofitting guidance of SCCW based the simulation results and the developed optimization model.
- Based on our preliminary results, immediate and significant savings in peak-time cooling-energy consumption are expected, considering the large inventory of existing low-performance buildings in the US.

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Questions ?

IMPACT OF AIR LEAKAGE THROUGH RECESS LIGHTING FIXTURES ON THE ENERGY PERFORMANCE OF RESIDENTIAL BUILDINGS – A CASE STUDY

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Abstract

The actual energy performance of buildings depends on not only the design criteria but also on the construction quality of buildings. Many design assumptions can be invalidated by unexpected construction quality issues, and lead to large variations between the designed performance and the constructed performance. Though important, very limited research, especially quantitative study, is found on evaluating the impact of construction quality issues on building energy performance. In this paper the construction quality issues of residential buildings in the United States is discussed, along with reviews of building envelope related research. A case study on residential attic construction is presented to illustrate how construction quality affects the energy performance of attics. The case study utilized 3D computational fluid dynamics to simulate air leakage issues in recessed lighting using different boundary conditions. The results of the case study suggest that some seemingly insignificant construction quality issue can cause significant increase in energy consumption of residential buildings. The paper provides scientific evidence to help residential construction industry to improve the construction quality of residential buildings in the United States.

Keywords: construction quality, energy performance, residential building envelope, attic, recessed lighting, CFD

1 Introduction

Unintended air leakage through buildings' envelopes is a common issue in the design and construction of single-family residential buildings in the US. In many cases, unintended air leakage can lead to significant extra energy consumption [1]. When air leakage leads to

excessively energy consumption burden for a building, it can cause the heating or cooling load surpassing the ability of HVAC system in a building so as to affect the thermal comfort in the building [2, 3]. In addition, Leaking airflow may contribute to moisture problem which can “impact the long-term performance of the building material and the building’s structural integrity” [2,6,7,8].The unintended air leakage issues exist in both new and existing buildings. This paper will discuss particular leakage cases associated with recessed lighting fixtures installed in the ceiling area, which is next to the vented attic space. The boundary condition settings used in the case studies are very typical in the US.

In the majority of states in the US attic are required to be vented to reduce moisture problems. Insulations are commonly used to cover the whole ceiling area from the attic side. One problematic air leakage area is from indoor space to attic space through the canister vents of the recess lighting fixtures, even when the lighting trim is properly sealed. When recess installed between indoor space and attic space, under the stack effect, the perforated recessed light fixtures may become small “chimneys” and contributes to great heat loss. In one case, a large house located in Harrisburg, Pennsylvania suffered ice dams and unusual high fuel pay. After investigation, air leakage of the recessed lights was identified to be the main reason [9, 10].

There are two types of recessed lighting fixtures, IC-rated and non-IC rated (Fig 1). IC-rated fixtures are allowed to be in contact with insulation, thus are very common in residential buildings; non-IC rated housing fixtures should keep a certain distance, at least 3 inches, away insulation over the ceilings or be installed in non-insulated ceilings, therefore, are more often in commercial buildings. For security, bulb installed in the recessed lighting had better not exceed 75 watts, especially for the IC-rated recessed lighting which often directly contact with insulation[9]. IC-rated and non-IC rated recessed lighting are often designed to have perforated canister to dissipate heat generated from the light bulb[10]. And thus air leakage is quite common through canister’s openings.

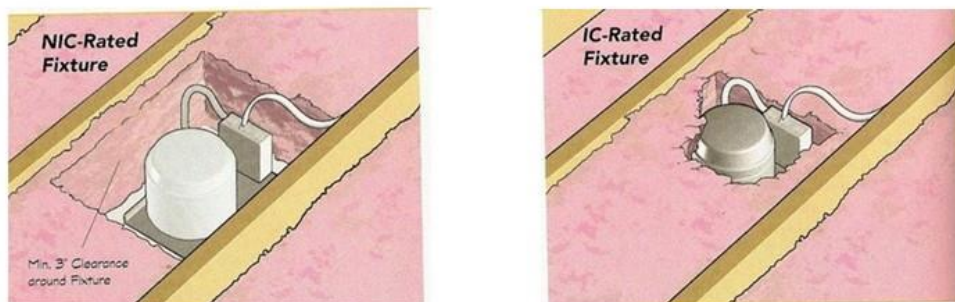


Fig. 1 Non IC Rated Fixture and IC-Rated Fixture (Source: <http://www.single-family-home-remodeling.com/recessed-lighting.html>)

Using infrared camera, leaking areas in the existing residential buildings can be easily detected. However, it is difficult to measure and quantify the air leakage using infrared camera. In this paper we employed a numerical approach, 3D computational fluid dynamics (CFD) method, to simulate air leakage in the recessed lighting to quantitatively investigate recess lighting fixtures’ impact on energy performance of residential building. Please note the authors only study the leakage phenomenon through perforated canisters when the light bulbs are not on. The light-bulb-on cases can be further studied in the future.

2 Numerical Model

An attic with sixteen square shaped recessed lights is simulated in this case. Due to the buoyancy stability of the attic ventilation as well as the symmetry in both geometry and boundary conditions, a quarter of attic is used in the computational domain to achieve computational efficiency. The schematic of heat transfer mechanisms in ventilation attic is shown in the Fig. 2. Both the convection and radiation are considered in the simulation. In order to simplify the simulation, 3D shapes of roof and ceiling trusses, as well as the thickness of the insulation are not considered, the computational domain is only occupied by air, which is assumed to be a Boussinesq fluid.

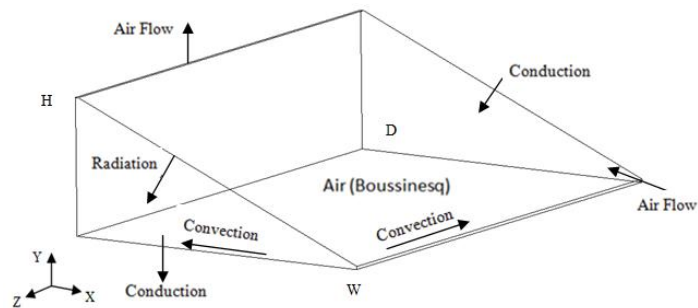


Fig. 2 Schematic of heat transfer mechanisms in ventilated attic

The detailed schematic diagram of recess light is shown in the Fig. 3. The length, width, and height of the attic simulated in the model are 6 meters, 4 meters, and 1.677 meters respectively, corresponding to a roof pitch value of 5/12. Each recessed light is supposed to be non-IC rated, and have four 2 cm x 20 cm openings of air leak surround each side of the recessed canisters.

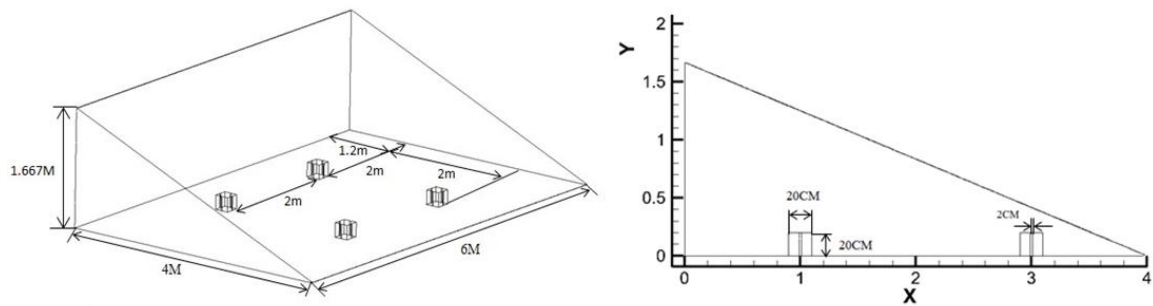


Fig. 3 Geometry of attic with recess lighting

Natural ventilation through the attic is considered in this case. Ventilation ratio refers to the net free area, such as soffit and ridge vent regions, divided by the deck area of the attic[11]. In this case, the ventilation ratio is supposed to be 1/200. The insulation level represented by R-value is also considered at different locations of the attic in this model. As shown in Tab. 1 and Tab. 2, different ambient air temperatures in winter and summer conditions, as well as R-values are assumed in different regions. The emissivity of a material is the relative ability of its surface to emit energy by radiation. Since the impact of radiation in winter is insignificant, emissivity is only considered in summer condition.

Tab. 1 *Winter boundary conditions*

	Temperature	Thermal Conductivity	Emissivity
Roof	258K(-15°C)	R-1.2 (4.733W/m ² K)	/
Vertical Wall	263K(-10°C)	R-1.2 (4.733W/m ² K)	/
Ceiling (indoor)	293K(20°C)	R-20 (0.284W/ m ² K)	/

Tab. 2 *Summer boundary conditions*

	Temperature	Thermal Conductivity	Emissivity
Roof	345.15K(72.15°C)	R-1.2 (4.733W/m ² K)	0.85
Vertical Wall	315.15K(42.15°C)	R-1.2 (4.733W/m ² K)	0.85
Ceiling (indoor)	297K(24°C)	R-20 (0.284W/m ² K)	/

3 Results and Discussion

3.1 Winter Condition

The contour of temperature and streamlines of the recess lights in winter condition are shown in the Fig. 4. As shown clearly from streamlines, there are four areas with high temperature on the roof which are caused by the hot leakage air from the openings around recessed lights. The air enters through the bottom of the canister has a higher temperature which means a lower density and results in rising up easily. This phenomenon is also found in the real observation as shown in the Fig.5.

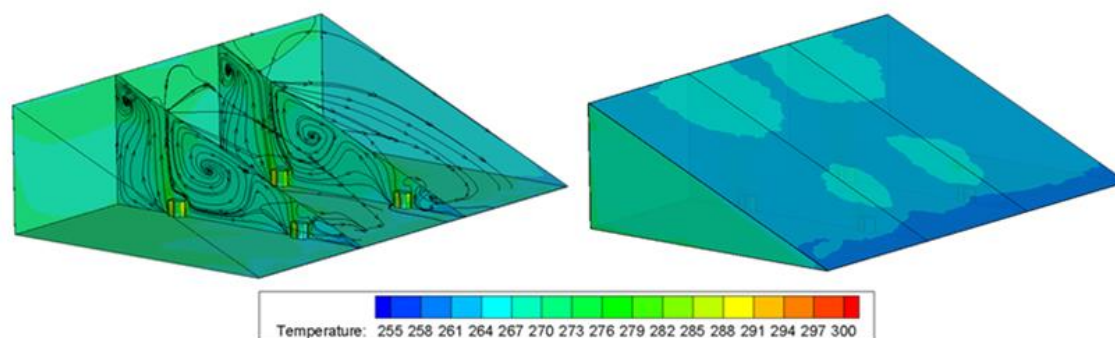


Fig. 4 *Streamlines and Contour of Temperature in winter*



Fig. 5 Excessive Humidity Damages Attic(Source: <http://www.hankeyandbrown.com/icedams>)

3. 2 Summer Condition

In summer, the temperature of the roof in summer is relatively uniform as shown in temperature contour of Fig.6. As shown from the streamlines, the air entering through the leakage at the recess lighting has a lower temperature which means a higher density. After mixing with the hot air entering through the soffit, the temperature of the air goes up and air rises to leave the attic at ridge.

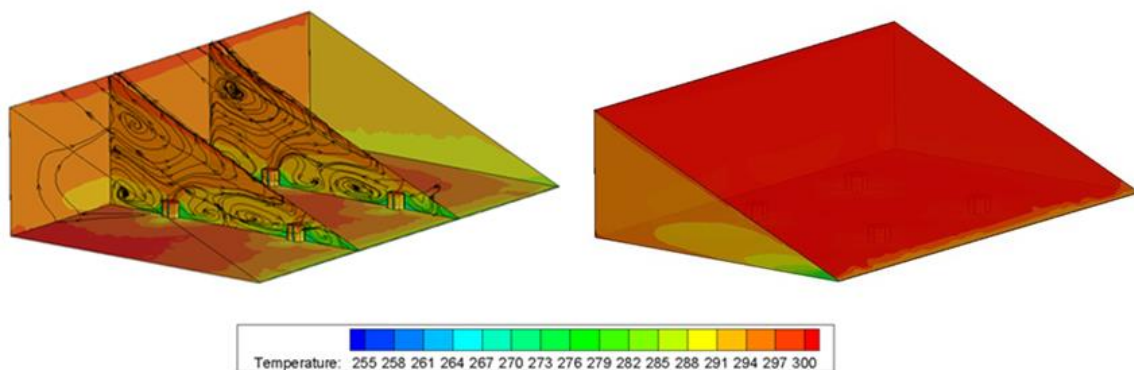


Fig. 6 Streamlines and Contour of Temperature in summer

3.3 Results

The results of air leakage in the recessed lighting fixtures in winter and summer condition are listed in the Tab. 3. The positive value of the heat transfer rate means the heat transfer from the indoor to the attic. The negative value means the heat transfer from the attic to the indoor. High heat transfer rate at recess lighting leakage is found both in winter and summer conditions, which indicates significant energy loss despite of good ceiling insulation R value.

The ceiling heat transfer rate is larger in summer than that in winter owing to the higher temperature gradient in summer. However, in winter the heat transfer rate of the leakage area in recess lighting tends to be greater, thus the effects caused by the air leakage in recess lighting is more significant in winter. Since the “stack effect” is more intensive in

summer, the mass flow rate of air leakage in recess lighting and soffit in summer is larger than that in winter.

Tab. 3 Comparison of winter and summer condition

	Winter	Summer
Heat transfer rate through ceiling (W)	161.12	-218.4
Heat transfer rate through recess lighting leakage (W)	105.72	-55.8
Mass flow rate at recess lighting leakage (Kg/s)	0.0209	0.0355
Mass flow rate at soffit (Kg/s)	0.024	0.048

4 Conclusions

We use a simple ratio of heating or cooling loss between lighting fixture leakage and through ceiling heat transfer to measure the significance of lighting fixture leakage. In the simulated simple case, 16 recess lighting fixtures on a 12x8 square meter R-20 ceiling, the ratio of winter heating loss of 106:161 is very significant. Although, in summer, the ratio of cooling loss of 56:218 indicates cooling loss is less compared to heating loss in winter, it is still significant considering the relatively small area of the lighting fixtures. Based on the case study of recess lighting discussed above, we can conclude that some seemingly insignificant air leakage issues can cause significant increase in energy consumption of residential buildings. These air leakage issues may come from design or construction in either new or old buildings. More studies are needed to improve the scientific knowledge base of design and construction quality of residential buildings in the US in order to increase the energy efficiency.

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