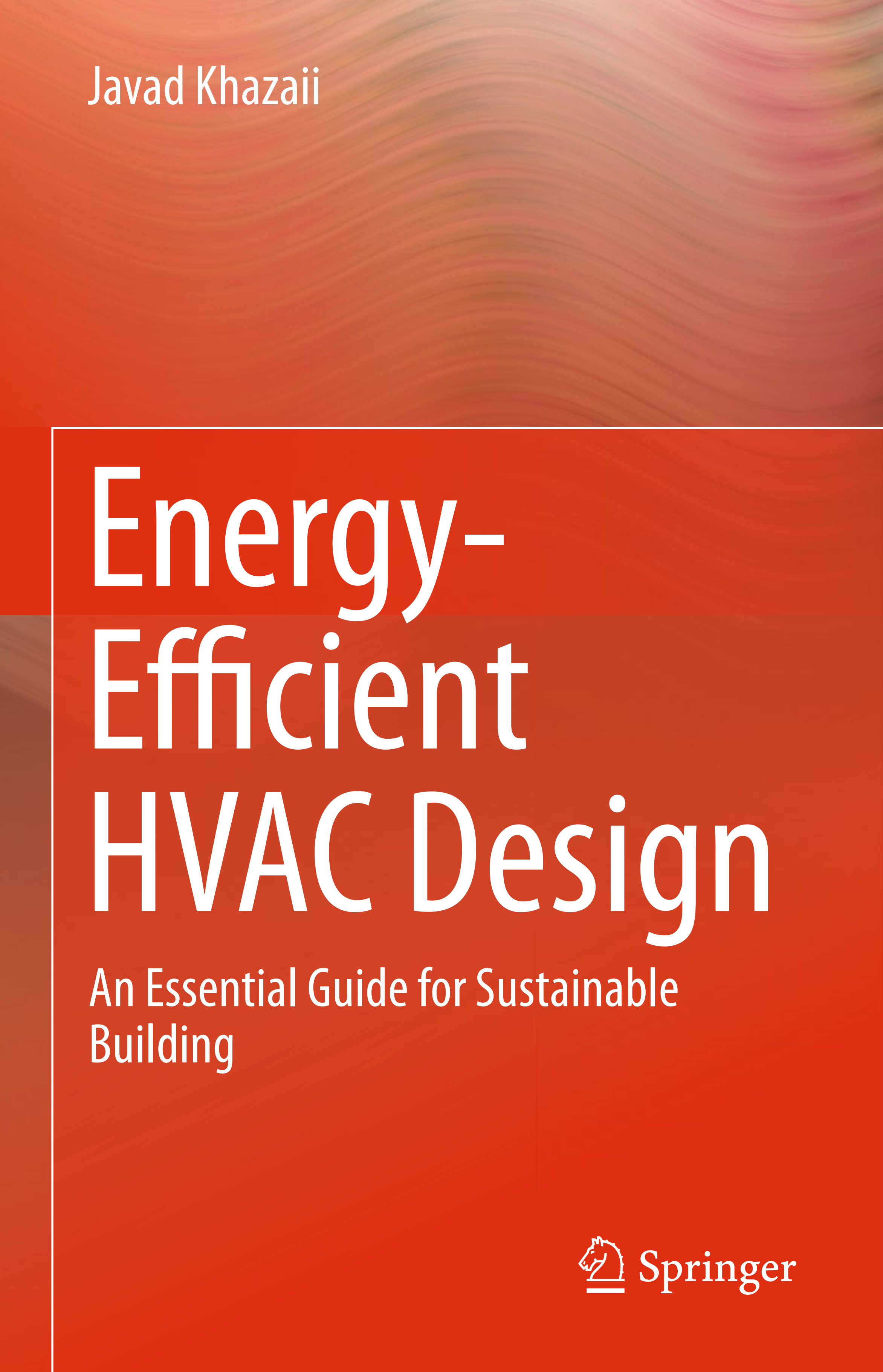

Javad Khazaii

Energy-Efficient HVAC Design

An Essential Guide for Sustainable Building

Springer

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To my beautiful wife Hengameh

Preface

Sustainability and green building design have become powerful household concepts in the past few years. Almost everyone has his or her own ideas about global warming, renewable energy, and high-performance buildings. The copiousness of available information and resources overwhelms and even confuses not only young professionals but even seasoned architects and engineers who are in the frontline of designing energy-efficient sustainable buildings. Therefore, my main aim in writing this book was to present the most essential concepts and necessary tools to young and experienced professionals in order to enable them to perform more in-depth study, make proper decisions, and therefore design and construct high-efficiency sustainable buildings. The topics covered in each of the chapters of this book can be developed to form lengthy books by themselves, but my aim was to introduce the main concepts and not to bore readers with too many details. However, references provided throughout the book would prove helpful to readers who would like to have more in-depth knowledge of the topics covered. The book is mainly targeted toward mechanical and architectural engineers, with a focus on heating, ventilating, and air conditioning systems of building technology. Throughout the book, I have attempted to introduce readers to the most relevant topics for (1) communicating and categorizing knowledge about sustainable and energy-efficient buildings; (2) finding and implementing the significant standards, rules, and regulations for designing and constructing these buildings; (3) understanding the major systems and their associated controls; (4) getting familiarized with the designing and energy modeling tools to predict the estimated performance of these buildings; and (5) recognizing sources of available renewable energies to be utilized for electricity generation or even direct conditioning for these buildings. Finally, I have discussed (6) the concept of uncertainty, which though not a new concept in the academic world has not been developed fully to the extent of being available for industry-wide use. Of course, in the current professional world it is still a completely foreign concept with regard to the way that buildings are designed and their energy consumption is estimated. This can therefore be one of the most effective decision-making tools for estimating energy consumption and therefore in designing buildings.

Some of the chapters presented in this book have been dedicated to describing the current state of building design and construction systems and organizations. On the other hand, a few of the chapters have been written in order to encourage enthusiastic students and engineers to get involved in developing newer and less developed areas. All the sections have been written with a focus on energy-efficient and sustainable methods for the design and construction of buildings.

What distinguishes this book from the rest of the books available in the market is its comprehensive yet straight-to-the-point nature. I have tried to present the concepts and knowledge which are absolutely necessary for students and professionals in the field without diverging into common and century-old thermodynamics, heat transfer, and fluid mechanics formulas which are widely available in most other books. In a nutshell, this book gives shape and organization to readers' understanding of the main energy-related issues relevant to the modern HVAC industry, that is, it focuses on practical material which is missing in other available books.

I hope that this book can be of help to students and professionals who are at the beginning or middle of their professional journeys to design and construct more energy-efficient buildings and therefore contribute to building a sustainable and better world.

Marietta, GA, USA Javad Khazaii

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I would like to acknowledge the support and influence of a few people in my life, which proved to be invaluable in writing this book. Above all is the memory of my beloved father who inculcated in me the love for education and knowledge from the early years of my childhood. I would next like to salute my professor and mentor Godfried Augenbroe who taught me how to research effectively. Thanks to Dr. Reza Nakhaei Jazar who, from the day I have known him, has encouraged and guided me wholeheartedly in my academic journey. Thanks also to my brother Dr. Ali Khazaei whose endless support and engaging intellectual discussions helped me develop the drive and passion for my scientific achievements. Finally, I would like to express my gratitude to the two ladies in my life, my mother Efat and my wife Hengameh; without their patience and encouragement none of this would have been possible.

Javad Khazaii

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About the Author

Dr. Javad Khazaii received his Bachelor of Science in Mechanical Engineering from Isfahan University of Technology (Iran) in 1985 and moved to the USA in 1990. For the past two decades, he has been associated with several consulting engineering firms in the design and modeling of HVAC and energy systems for different commercial buildings. He received his Master of Business Administration with a focus on Computer Information Systems from Georgia State University in 2002.

Dr. Khazaii received his Ph.D. in Architecture with a major in Building Technology and a minor in Building Construction from Georgia Institute of Technology in 2012. He has also been teaching Southern Polytechnic State University as an adjunct faculty since 2011. Dr. Khazaii has been a registered professional engineer in the state of Georgia since 1994 and a LEED-accredited professional since 2008. He has been a regular contributor to the energy modeling column of one of the most prestigious engineering journals in the USA for the past two years. He also won the first prize for the best building simulation in a team competition organized by the International Building Performance Simulation Association (IBPSA) in Glasgow, Scotland, in 2009.

Part I
Introduction

Chapter 1
A Challenging Task

Designing a building is a complex task requiring close cooperation among the architect and a group of engineers with different expertise, such as mechanical engineers, electrical engineers, and structural engineers. Up to a few decades ago the main target of the traditional building designers in general was to design a building that is beautiful, comfortable, cost effective, and capable of satisfying the building applicable functions. The focus of the modern era building designers in response to the world energy uncertainty and its increasing cost and adverse effects on environment has changed to not only satisfying these traditional design targets, but also minimizing consumption of energy in the buildings. This has imposed a big burden on the architects and engineers to change the way they have pursued building design. Now, not only they have to comply with common standards and codes such as building code and mechanical code, but also have to comply with the new regulations based on requirements that are set by organizations such as Leadership in Energy and Environmental Design (LEED) in order to surpass the energy saving thresholds that are enforced by energy standards such as ASHRAE standard 90.1.

Therefore being an effective architectural or Heating, Ventilating, and Air Conditioning (HVAC) engineer in the current environment is a more daunting task than it used to be a few years ago. There are plenty available books, handbooks, and guidelines in the current market that provide essential scientific and technical knowledge for students and practitioners in this field covering the technical aspects of building technologies such as detailed building load calculations, HVAC equipment sizing, and understanding the heat transfer and fluid mechanics laws that are necessary for predicting the physical behavior of HVAC systems. Also there are multiple published codes and standards that regulate different aspects of the practice of HVAC and architectural engineering, among them and specifically in the past few years energy and sustainability related standards that have become also essential knowledge for students and practitioners. Meanwhile after years of being involved in the HVAC design and building energy modeling practice and interacting with numerous young and experienced engineers, I found out that most of the newly entered architects and HVAC engineers to the professional world along with a large

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group of experienced practitioners are drowned in the ocean of the available information and do not have a complete and clear grasp of what kind of knowledge is really necessary for a real efficient and sustainable building design. Usually the younger professionals are more comfortable when they are working with software, but not only are not completely familiar with complicated aspects of the software they are using, but also do not have the adequate knowledge of how the actual HVAC systems work or even what entities regulate the efficiency of those systems. On the other hand in a few cases the older professionals not only are not comfortable to work with the software to be kind to say, but also are hesitant of specifying and designing the newer systems due to their more degree of comfort with design of the traditional systems. There is an empty space demanding for a holistic yet not too lengthy guideline that can point towards the missing skills and knowledge for both younger and older professionals to make them capable of acting efficiently in their practices, specifically when energy saving is the focus of the design. Therefore I felt that in the current market there is an immediate need for a source of information that can offer a balance discussion between the traditional and modern engineering concepts and topics that knowing them are now necessary for an architect or engineer to function with an energy-saving target mindset in the ever-changing field of building design. The target of this book therefore mainly is to provide the essential and necessary overall knowledge about applicable energy related references and topics for both students and younger practitioners to quickly familiarize themselves with the structure of the industry and to become more effective architectural or HVAC engineers in their professional practice.

This book is divided into an introduction and five major sections. In the first section (introduction) I have reviewed the logic and classification of the book subjects and targets briefly. In the second section I have introduced the concept of the integrated design and its importance for an energy conscious design. In addition I have discussed the concept and also the need for developing building specific knowledge categories. Categorizing knowledge helps to not only reduce the inefficiencies derived from unfamiliarity of the young and even experienced architects and engineers (design players) with the concepts in their trades, but also decreases these inefficiencies in relationships with different design trades in order to improve the energy efficiency of the design process collectively.

In the third section I have pointed to the most important codes and standards that set up the required rules and frameworks for building energy efficient design. I have discussed the performance based standards and design and have depicted the differences between that and prescriptive based standards and design as well. The importance of the indoor air quality which has become one of the most important aspects of sustainable design is also reviewed and discussed in this section. Finally I have closed the section by referring to the most important legal issues concerning the design team and discussed the provisions that are necessary for a defensive building design.

In the fourth section I have presented the general information regarding different types of the HVAC systems, important factors in HVAC system selection, and advance HVAC systems including an overview of hybrid ventilation system and control systems in order to help designers to design systems and employ control methods which result in achieving higher building energy efficiency targets. In this section I have paid special attention to components of the regular and advanced HVAC systems. In each case not only I have a brief description of the system, but also I have specified the sources of energy consumption in each system. This would help the readers to be capable of recognizing and relating these energy consumption sources back to the concept of uncertainty and decision making which its use in energy modeling process has been discussed in the final chapter of this book.

In the fifth section I have explained the basics of load calculations and energy modeling, along with a brief discussion about the potential renewable and sustainable energy production systems. I have finished this section with a discussion around the most common building energy efficiency scoring methods that are currently being utilized worldwide.

Finally in the last section I have discussed the concept of uncertainty and the requirement of including this tool in building energy modeling in order to quantify and manage associated risk in modeling exercise. This implementation is currently in early stages of development, and there is a vital need for commercial energy modeling software writers to revise their products to make them capable of performing risk based energy modeling instead of current deterministic modeling approach. A holistic probabilistic energy modeling tool if it is developed would be a very definitive step towards revolutionizing the way the industry looks at building energy modeling and design decision.

In summary the following topics have been discussed in this book:

Part 1: Introduction

1. A challenging task

Part 2: Collaboration

2. Integrated design
3. Categorizing knowledge

Part 3: Frameworks and standards

4. Frequently used codes and standards
5. Performance-based standards
6. Indoor air quality
7. Protective design practice

Part 4: Systems and controls

8. Types of HVAC Systems, and system selection
9. Automatic controls

Part 5: Energy modeling, sustainability scoring systems, and renewable energy

10. Energy modeling
11. Sustainability and energy conservation scoring systems
12. Renewable energy and sum-zero energy buildings

Part 6: Uncertainty and risk management

13. Uncertainty and risk management

As it can be seen covering such a broad field of concepts in one book could be a challenging task. I have given it a shot and if I can only be successful in achieving a few general objectives I would be very happy and satisfied with results of my work. The first objective is to remind the students and young engineers about the importance of team work, not only in their own firm, but also with the members of other firms working on completing a design or construction project together. Keeping this concept in their mind can help them to see themselves as part of a lot larger community and feel responsible for the success or lack of success of the projects in hand and even the whole industry. Everybody is important and should contribute to success of the project and industry advancement as much as they can and as early as they can start.

The second objective is to highlight this concept that what is actually being done in the professional realm even though it is advanced, but is not complete or perfect in any ways. It requires continuous improvement and these are the students and young engineers that should take responsibility to improve the existing methods and to invent new ways for the advancement of the industry.

And the third objective is to reemphasize on the fact that qualitative advancements and changes would not be likely without a continuous relationship between knowledgeable professional work force and the advanced academic researches. To reach this goal either more students should stay longer in the schools, and reach higher levels of educations while working in the industry, or professional firms should start creating research departments, so the new and exciting academic methods can be introduced, tested and make advancement in the real professional world. Working of each of these two groups in a vacuum is not an option any more.

Part II
Collaboration

Chapter 2
Integrated Design

2.1 Conventional Design and Construction Strategies and Players

The main players in a conventional (traditional) method of designing and constructing a building are the building owner, architect, engineers, commissioning team, and general and subcontractors. Code reviewers and authorities having jurisdiction that review the design documents and upon approval of the design issue building construction permits are the secondary group of the players. Finally last group of the players are the firm's attorneys that handle the firm's lawsuits and prepare educational presentations for the firm managers and employees, in order to familiarize them with the basics of defensive and protective architectural, engineering, and construction practices.

In a typical traditional design and construction process owner's needs and expectations are primarily communicated to the architect. Architect then designs a preliminary building and depending on the size and type of the building, employs a group of engineers including structural, civil, HVAC, plumbing, electrical, fire protection, fire alarm, audio-visual, and acoustical engineers to design the building engineering aspects. A close communication among all these players is essential for delivering a successful design product.

Design process in a typical consulting engineering firm usually starts with reception of the architectural preliminary plans and guidelines. These preliminary plans as a minimum show the orientation, function, and sizes of each space in the building as it is intended by the building owner and as it is envisioned by the architect. Usually at this time there is only sufficient information for a preliminary engineering design. Different design engineers always need considerably more information to be capable of performing their expected designs meaningfully. This additional information includes items such as building sections and elevations, number of

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occupancy, lighting, equipment, reflected ceiling plans, fire-rated walls and partitions, and the characteristics of walls and glasses. At the same time, design engineers have to provide feedbacks to the architect which based on this data the architect would be able to complete his design. Samples of this data are duct and pipe chase requirement, mechanical, electrical, plumbing and fire protection space requirement, etc. Based on the quality and effectiveness of the architect and engineers this information exchange could take place either quickly or consumes some considerable time. In some unfortunate situations, when one or more of the involved parties are not well experienced, building design could be performed without complete and accurate exchange of some important information. This most likely would lead to a problematic and troublesome construction process.

After all the coordinations took place and was included in the building design, the final design product will be presented to the code reviewers and authorities having jurisdiction for their approval before being handed to the general contractor for construction. General contractor is usually selected through a competitive bidding process.

The selected general contractor then hires different subcontractors to construct different parts of the building. One more time a very close communication among the architect, engineers, general and subcontractors is needed to make delivering a successful final product to the owner possible. As the general contractor and his subcontractors become involved in the construction process, their first task is to provide construction shop drawings. These shop drawings are produced based on the information available in the construction documents, and later will be used for constructing the actual building. Shop drawings are a set of coordinated drawings that contractors provide from over laying all the architectural and engineering drawings at each building part. Contractors send these shop drawings along with selected equipment data back to the design team for their final review and approval of its exact equivalency with the design intents, and after receiving an approval from the design team use it to start the actual construction phase. During the construction process, design team in pre-approved time intervals performs a few site visits, and informs the general contractor if there is any construction deviation from the design contract documents. When construction finishes the design team performs the final site visit and approves the building for occupancy. Again at this stage and based on the quality and accuracy of the contractors and design team site visit performances, construction process could be completed either smoothly with a high quality, or poorly with unchecked and uncorrected mistakes.

Architects and engineers usually prefer this method of design and construction because they get to perform a design with much higher than what is set as the minimum quality required by the codes and standards. After contractors got the project based on becoming the lowest bidder, they may rely on collecting more money through issuing request for information (RFI). This would require a successful demonstration that design has not been clear and complete when they bid the project, and they have calculated their estimated cost based on uncompleted design document.

Due to the structure of the market another processing method has been received more attention in the industry in the recent years. In a design-build process only the general contractor is selected directly by the owner, and architect, engineers and subcontractors are then added to the team by the general contractor. In this process from the start of design the general contractor and his subcontractors have interaction with the architect and the engineers to provide a design that has all the minimum code compliance acceptable quality with a pre-negotiated guarantied cost. Owners that do not plan to keep the building ownership to themselves after completing the building construction may prefer this method, because in this case spending minimum first cost may be more important for them than a building with higher quality and better future performance. Throughout this process generally most of the upgraded designs proposed by the architect and engineers that could add to the value of the building and therefore total cost of the project is ruled out by the general contractor in order to keep the total project cost within the pre-agreed upon budget.

2.2 Integrated Design

A building is made of multiple components and systems, which each one is designed and installed by a different professional. A small change in characteristics of any one of these components or systems can have a considerable effect on the other components and systems performances. For example a small change in the heating characteristics of a typical building glazing system has a dramatic effect on HVAC system cooling and heating equipment sizes, ductwork and piping network size, power requirements, consumed energy, day-lighting strategies and lighting design, mechanical space requirement, and noise level in the building. Also selecting how to orient the building on a site has a lucid effect on where to locate the mechanical rooms and fresh air intakes in the building, and building ventilation, lighting, day-lighting, noise, and air quality control strategies. This not only implies a close co-operation among the architect and engineers, but also requires their vast cross-discipline knowledge.

It has become obvious that the traditional way of design in which each individual (trade) player was working in a vacuum for most of the design and construction time and everybody was relying on either architect or general contractor project manager to coordinate and solve all the conflicts is not an efficient method of design and construction to be pursued any more. In an integrated method every individual should not only be in continuous contact with the architect or construction team leader, but also shall be in continuous information exchange with all the other players. This communication is most critical specifically in the early stages of the design. Experience has shown the earlier the need for changing design or construction is discovered, the less burdensome the financial effects of the design change will be on the project itself, and also on all the involved parties as well.

Usually the best way to manage a successful integrated design effort is to get all the lead design players together at the beginning of the project and establish brainstorming sessions to study the building and collect all the player's inputs, requirements and concerns on cross-related issues and use that to make the initial design based on an overall agreement among all the involved parties. Such efforts promise a correct initial design direction along with eliminating possible multiple designs of the same system due to discovering its conflict with other team member's design approaches later and along the way. Such actions should not be limited just to the initial sessions, but they should continue throughout the rest of the design process regularly. Such collaborative efforts will help the team to find and solve the probable conflicts throughout the design and construction process much faster and with much less financial and environmental burdens.

An example of an integrated design emerging out of the integrated design brainstorming sessions can be integration of building skin design by the architect, daylight illumination by the electrical engineer's and HVAC system by the mechanical engineer. In this approach the architect optimizes the design of the building envelope system in such way that maximizes the use of day-lighting in the building, by specifying high-quality glazing system. This technique helps the electrical engineer to reduce the use of artificial lighting during the hours of the day that it is possible to replace design lighting with natural light in the building. At the same time the HVAC engineer gets the benefit of lower artificial lighting load and higher quality glazing system in the form of smaller HVAC equipment size requirement. As the result of smaller HVAC equipment the architect gets the benefit of additional usable spaces and higher ceilings heights in the building that obviously adds to the beauty of the architectural design. Electrical engineer also gets the benefit of smaller generators due to smaller size HVAC systems and of course lighting system that would collectively helps the team to bring the project cost and its environmental negative effects lower. Such benefits cannot be realized without engagement of all the team players in early interactions and their collective efforts.

In summary the integrated project design and construction should be looked at as a method of working on and completing a project by maximizing the project outcome for the owner and minimizing undesired effects on the environment. Most important element of this process should be managing the waste (specifically energy waste) and increasing the design and construction efficiency. This cannot be achieved other than by utilizing the maximum skills, knowledge, and resources of the involved players. An important step in performing a well-executed integrated project delivery is proper cost, schedule, quality, performance, sustainability goal settings, and developing procedures to measure and verify the success of each outcome. For a detail discussion on the principles, procedures and benefits of an integrated project delivery refer to "Integrated Project Delivery: A Guide; version 1; 2007; AIA National/AIA California Council; The American Institute of Architects."

A typical integrated design process and the proposed required steps along with a sample design charrette matrix has been presented in Appendix "H" of ASHRAE standard 189.1, 2011 (ASHRAE 2011). In this specific charrette each factor which is believed to be dedicating to the high performance of the building is graded between 1 and 10 in order to create an overall advantage of one system over the competitive solutions. Of course this is not the only way of utilizing integrated design and many other grading methods depending on the specifics of the projects also can be utilized.

2.3 Energy Conscious-Integrated Design Approach

Delivering a successful energy conscious building construction project also should start with an integrated effort from the early stages of conceptual design and continue throughout the whole process of delivery and even beyond it. A well-planned scheduling and outcome targeting should be utilized in order to specify, monitor, and verify each parties responsibilities at each step along the project life to guarantee a successful outcome. The desired sustainability goals and energy saving measures should be known as early as possible, since adding a new sustainability characteristic to the building in the middle of the design could be very costly. As an example, energy consumption monitoring for different energy users in the building is always a very good sustainability measures to have in the building specifically in order to monitor the real energy consumption of the building sections after the building is occupied by different tenants. From the point of view of an electrical engineer wiring the electrical power in the building should be designed in a specific manner to comply with this requirement. If from day one the owner and the team agree upon achieving this desirable measure, the cost of the design and construction would not be affected considerably. But if the building power wiring is designed or even worse is installed without expectation of achieving this measure, and sometimes down the road a decision is made to add this function to the building sustainability system, then the cost of design or constructing the change into the under construction building would be dramatically higher.

As I have mentioned earlier in a successful integrated design all parties including the owner, the design team, the construction team and the commissioning team should be actively involved in all stages of the project. Different stages of a project delivery are usually referred to as conceptualization stage, design development stage, design stage, construction stage, and post-occupancy stage.

Conceptualization stage is the earliest stage that the design and construction team meet the owner and get familiar with his expectations of the building and also the project budget. There are many examples of the building designs that were started with a very high level of energy saving factors conceptualized in the early stages of the project implementation, just to be removed from the scope of the project due to lack of harmony between the design team imagination and the owner's budget. The design and construction team should in detail study the level of sustainability and energy saving that the owner desires to include into his building. Design team then should propose the possible systems, designs, material availability, and more important the cost associated with these factors to make sure that enough budget is available for designing and implementing these measures.

In design development stage, design and construction team should finalize the sustainability factors and level of expected performance from the building with a realistic input from all parties. A simple but complete design of major building systems and an early stage energy model should be presented that clarifies all the outcomes and associated cost for the expected performance of the building. Agreement of the owner of the project on selected systems and expected performances among the other possible options presented by the design team, and preliminary input from manufacturer's regarding their capability of delivering equipment that can provide the expected performance within the project assigned budget are other major milestones in this stage.

In design and construction stages all the building systems including its sustainable characteristics should be incorporated in design and construction of the building, and compliance of the building with all the expectations, performances, and codes should be verified. Performance of the building should be calculated and finalized via completion of the energy modeling exercises.

The post-occupancy stage which is as important as the other stages in realizing the performance of the building should include continuous engagement of the owner of the building in educating of the occupants and building management crew to make sure the building performs as the design intended to. The building owner shall oversee to make sure a proper service execution, and stay in continuous engagement with the design and construction team regarding monitoring and reporting the real performance of the building, and comparing it with the design intentions. If corrective measures are required it should be coordinated between the owner and the design and construction team to bring back the building to the proper operation and performance level.

2.4 Other Tools

Building Information Modeling (BIM) which is a digital shared knowledge resource for support of the decision making and designing a facility has taken a significant step in improving parts of the processes that was discussed in this chapter, but until all individual players think and act in-line with integrated design spirit, a real efficient design and construction procedure would be very hard to be performed even with advance software.

Creating design and quality control check lists by the firms are among other successful strategies that can be used as part of an integrated design and construction effort also. Some firms gather, update and complete their check lists as time goes by, which helps the individuals to refer to these lists for their designated responsibilities and required coordination with all other parties during the life of the project. Such checklist could be carried on to the brainstorm sessions in order to help even higher levels of success in integrated design approach.

In the next chapter of this book I will discuss the concept of organizing knowledge that if it is implemented correctly can have significant positive consequences on the improvement of a collaborative design processes.

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ASHRAE (2011). ANSI/ASHRAE/USGBC/IES Standard 189.1-2011. Standard for the design of high-performance green buildings, except low-rise residential buildings. Atlanta, GA: American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., and U.S. Green Building Council

Chapter 3
Categorizing Knowledge

3.1 Knowledge Management

Patrick Lambe in his book "Organizing Knowledge: Taxonomies, Knowledge and Organizational Effectiveness" (Lambe 2007) has beautifully depicted the way that people use classification in most of their daily functions. These classifications can be as simple as recognizing the fact that during grocery shopping when we see fruits we recognize that we are near the vegetable section to more complicated conditions such as when we are searching for finding an e-mail from a specific person in a specific project sub-folder in which all the e-mails from the people that are participating in that project have been collected.

Taxonomy is a method of organization and classification of knowledge. Similar to any other field, knowledge management is an essential tool for every firm or individual engaged in building design and construction in order to make the most utilization of the existing knowledge and available resources for his benefit. To create such useful resources, the first step is to generate or gather relevant knowledge of the field, and then, be capable to classify that in such manner that has the most relevance to the firm target. Originally taxonomy was created for categorization of species in natural science, but recently it has found its path to different areas such as computer and business sciences as well. It has really grown to be the method of categorization of science, information, etc. in a parent–child, or general-specific pattern. In such organizations, every element in the specific section has all the characteristics of the general section in addition to a few extra characteristics. For example it can be said that all the chillers are cooling generating equipment, but all the cooling generating equipment are not chillers. Availability of such categorizations in the field of engineering would have specific benefits for the younger engineers and architects in order to make them capable of capturing a better overview of their field knowledge vastness and therefore their expected responsibilities.

Without organized information the inexperienced users most likely would be confused in finding proper answers to even the simplest questions such as how,

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where, and when one can find and should use relevant information. Even experienced users may lose the chance of accessing some of the latest available knowledge and tools by just not knowing about existence of such resources. Practically different methods of generating powerful taxonomies or categorized knowledge are methods such as lists, trees, hierarchies, and system maps. Patrick Lambe in "Organizing Knowledge: Taxonomies, Knowledge and Organizational Effectiveness" (Lambe 2007) has a deep discussion about taxonomy in general and also methods of generating a powerful taxonomy.

Let me note here, and as I stated earlier since originally taxonomy was generated for the categorization of the living species, using this word in some conditions may create a noncompliant concept for our application. Therefore I will use categorized knowledge in the rest of this book instead of taxonomy, in order to ease some of the attached concepts to taxonomy that I do not intend to emphasize here.

Clearly categorized knowledge is not only a very helpful tool for educational purpose in colleges, but as it was stated earlier it also can be used efficiently for educating the younger group of professionals in the work place as well. Consider a new young employee who is recently hired by a company. For him to learn how to perform his duties at the new position, he usually and solely relies on the quality and quantity of the transferred knowledge from his direct supervisor to get him familiar with the new job and its requirements. If for any reason the direct supervisor is not willing or not capable of quickly and effectively introducing the new employee to the concepts, relations, and available tools, this new employee will have a very hard early months and even years at this position, and it may even cost him the job as well. This not only hurts the employee, but also hurts the employer, since this implies continuous change of employees and as a result losing time, money, effort, and even reputation. On the other hand, if the whole necessary body of knowledge, tools, and information required to understand and perform the expected job is stored in one location and this information is immediately accessible through a well-designed categorized knowledge source, the new employee will be able to retrieve and use it and make his transition to the new position as smooth as possible.

Benefits of a proper categorized knowledge document can also be realized when a group of professionals or scholars that are working on a project, or writing a thesis, a book or putting together a research document, specifically if they are working from different locations. If these people create their own subject related categorized knowledge resource before starting the actual work, and use and update that throughout the project, it is obvious that the final product will be more unified and consistent.

3.2 Community of Practice

Etienne Wenger in his book "communities of Practice, Learning, Meaning and Identity" (Wenger 1998) has a fresh and in depth look to the process of learning. According to him the process of learning neither should start only when the students enter the class nor should stop when they leave the class. Instead, the process of learning should be looked at as a full time social event in which our learning skill develops by experiencing, doing, belonging to, and finally becoming part of a community of practice.

The process of learning as a social event for the field of building design and construction which comprises architects, engineers, and contractors as the main participants and many others as it has been discussed earlier in this book can be explained based on the Etienne Wenger's model. To achieve this target, the way of characterizing social participation of design and construction field participants as a process of learning then can be described by the following explanations.

The first definition is the process of learning by negotiation about our experiences including our projects, findings, innovations, and mistakes. Nothing can help a professional better than learning lessons from other's mistakes. Some firms keep a records of what has been the source of problem in previous designs and of course what the solutions have been to those problems. Therefore everybody in the firm can refer to these records later and learn from the previous mistakes. Some firms dedicate special teams to quality control of the projects as their sole responsibility. Such teams have the advantage of seeing many repeated mistakes in different designs and quickly locate and underline them. The original design team members then can learn from these quality controls review comments. When a group of engineers in a firm start to design for example a new performance center which has never been done by them, it always pays off to spend some valuable time and talk to other engineers in the firm or even with other engineers, architects and even contractors that have previous experience in designing similar projects. A reputable contractor or an ally engineering firm can communicate their previous experiences with other engineers who had failed to perform a successful design, high-lights the sources of problem and even offers the best solutions based on previous conflicts. It is also very helpful to look back in the history of similar projects if it is accessible in their own firm. Going back through emails and records of similar projects and talk to old project's managers or engineers, even Internet search helps the design team to understand what has been the source of success or lack of success of such projects. All these communications, studies, negotiations, and learning should happen even before the design team actually starts their new design. In fact this process should resemble having many training sessions before the actual design. The more training is done the higher the chances are that it will result in a more successful project and fewer problems. A very good example of another similar process is what in industry is known as hiring and training co-ops while they are still in the school. These co-ops periodically work in the engineering offices for a minimum pay, but what they learn here makes them ready for work as soon as they are graduated. Of course during period of their hire as co-ops, they still are not ready to produce professional products. What they do during their attendance in the engineering firm is experiencing. They observe, question and help the professional engineers to produce real-life design products. This can simply be defined as the first step in the long process of learning.

The second step is the learning by talking about, improving and criticizing the shared sources, frameworks and perspectives that can sustain mutual engagement in action. This process can be included of periodically updating codes and standards, renewing design processes, designing better software and solutions, and producing new guidelines. Of course contributing to construction and advancement of proper categorized knowledge resources also belongs to this level of learning process. Such steps can be taken at least when the experience of a young architect or engineer increases enough that he begins to have a relatively strong grasp of the required knowledge to perform his duties. At this point he can ask questions that are not just for the purpose of finding the available answers and current processes, but are targeted to criticize, change and improve the current processes and methods being performed in the work place, or even industry-wide. Criticizing how the process of a specific design calculation or energy modeling is done, and trying to offer better replacing approaches fall in the same category of learning process. As the new generation of engineers with higher understanding of the programming languages enter the professional work force, and along with the practical experience that they are absorbing and of course supervision of the more experienced engineers they are set to improve the older, and more traditional ways of engineering data collection, calculations, design, and production.

The next step is becoming more educated by belonging to and participating in recognizable organizations. The participation in relevant organizations not only can increases the knowledge of the participants, but also can shape up and renew the whole building construction community's knowledge as well, simply by introducing and exchanging the latest findings, knowledge and techniques in the industry. Participation of the architects and engineers in architectural and engineering communities and seminars participating in and even presenting scientific papers and presentations and recognizing noble professionals responsible for advancement in industry are a few samples of this process.

As the person's knowledge and experience accumulate, the final step would be completing the process of learning by becoming a new highly educated person which is capable of advancing the knowledge of the community meaningfully. The ultimate learning stage therefore is to become a highly educated and experienced professional that stands above the average crowds and acts as a tool for new generations to respect and look up to. These are the people who write books, bring new concepts, and invent exciting methods of design and construction that can change the shape and advance the whole industry. The ultimate target of the learning cycle is to generate such individuals.

Therefore the overall learning realm of all the involved entities in design and construction community of practice can be summarized as follows. For engineers and architects, their learning engagement is an issue of participating in and contributing to the practices of design and construction community. For design and construction community, it means that learning is an issue of advancing their practice and ensuring new generations of well educated members. And for design and construction companies, it means that learning is an issue of becoming effective and valuable as an organization in what they do.

3.3 Creating Proper Categorized Knowledge for Building Industry Community of Practice

What I have explained in the last few paragraphs in this chapter implies that the two concepts of categorized knowledge and community of practice have the potential to become the strong holding columns of the structure of the future building design and construction industry. Each individual in this community should feel responsible for generating or adding to the existing collections of categorized knowledge for the benefit of the whole community. These contributions could come from individuals seeking higher education, or based on every day work experience of other professionals.

The purpose of this section by no means is to create a complete categorized knowledge resource for the building design and construction community of practice, but it is just to present a starting point to be followed by the enthusiastic students and engineers to generate a relatively strong and applicable categorized knowledge resource for the benefit of the whole industry.

In order to create an overall categorized knowledge document for the building design and construction entity which is useful for training the new employees in both consulting architectural-engineering firms and construction companies, naturally the first step is to specify the main categories. For our approach it makes good sense to divide all the concepts, parameters and players that will be covered in this field into two non-overlapping main categories of (1) professionals and their functions, and (2) applications. It should be reemphasized here again that the following approach is not the only acceptable approach, and there would be many different possible approaches that could generate even more powerful results. Of course other categories can be selected by different individuals or groups interested in generating this tool for their own targeted purposes. By the way our first main category creates an umbrella for covering all the people (community of practice), their responsibilities, functions, and tools that they have to utilize in executing their tasks and the second category creates an environment for expressing building types, its components and design requirements. From here on we can generate secondary branches in order to develop explanatory information for each of these two main categories. Therefore the next obvious step is to categorize the major professional groups that are involved in building design and construction functions along with the individuals who are performing assigned tasks in each group. These professionals can be specified as architects, engineers, contractors, code officials, etc. The functions and duties of these professionals then can be investigated and summarized in detail format. This procedure will lead to generation of copious number of functions, duties and concepts that can be categorized and assigned to each individual. Since each member of this community of practice belongs to one specific trade category, it makes sense to start building our categorized knowledge by creating the main subbranches, such as HVAC, plumbing, and electrical. If at this time we turn our focus on to providing guidelines for each of these professionals the next step would be to specify all the functions and duties of each professional such as the HVAC engineer and HVAC contractor as a subset for HVAC field. Functions and duties of HVAC engineer can be described as performing design, writing specifications, performing construction administration, etc. Obviously the process can be continued by adding more details to the subcategories of each duty or function, such as providing subsets of drawing, calculations, energy modeling, and cross coordination with other trades for design category. The process can continue by adding all the energy saving strategies under design category. Furthermore a cross trades coordination process can be described in details that would help all the parties involved in this community of practice not only to become familiar with each other's functions, but also to find out what are their responsibilities regarding the rest of the community while working on the same projects quickly. To do so, maps of responsibilities for each trade versus other trades should be designed and added to the body of our categorized knowledge document. These maps for example should show all the responsibilities of the HVAC engineer in regards to all other disciplines. As an example HVAC engineer is responsible for providing equipment room sizes, vertical chase sizes, information for equipment and devices, and etc. which are necessary information for the architect. He is also responsible for providing equipment locations, regular and emergency power requirements, phase, voltage, and required power of all his equipment which are necessary information for the electrical engineer. After such maps are completed, it would allow a newly graduated, newly employed architect, engineer, and contractor to have access to the whole industry layout, the functions and responsibilities, the way to design, calculate, specify, and construct in early stages of his career. As it was said earlier it is not only to the benefit of the less experienced players but also helps the firms in order to quickly prepare their employees for being engaged in designing and building processes.

On the application side a building can be subdivided into commercial, institutional, healthcare, etc. Each of these building types has its own dedicated functions and therefore space requirements. For example the majority of the spaces in an office building can be described as open offices, private offices, conference rooms, etc. While the majority of the spaces in a healthcare facility can be described as patient rooms, operation rooms, laboratories, waiting rooms, etc. Each space then can be described in further details by describing the physical characteristics of the space and expected functions, equipment, occupancy, required cooling, heating, and lighting. This information then will be essential information for designers to calculate engineering requirements of each space.

By this time a rough overall system map has been created that each community of practice member could look at it, and easily recognizes the major applications and players and their major functions and duties in the course of a design and construction process.

The following snap-shuts (Figs. 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, and 3.7) show samples of an incomplete attempt for generating categorized knowledge for this field with an emphasis on the HVAC design and also energy efficiency branch. This could be developed into a much larger document covering all the aspects of HVAC design and further the whole industry concepts and functions. Of course such a comprehensive categorized knowledge cannot be generated without participation of all the parties involved as part of the building design and construction community of practice.

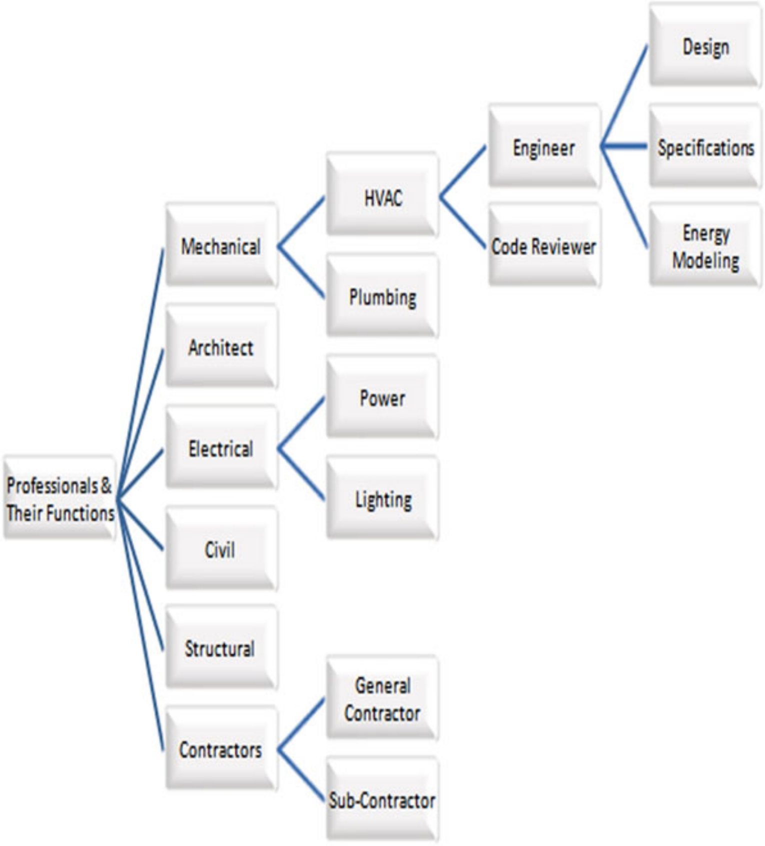

Fig. 3.1 Professionals and their functions

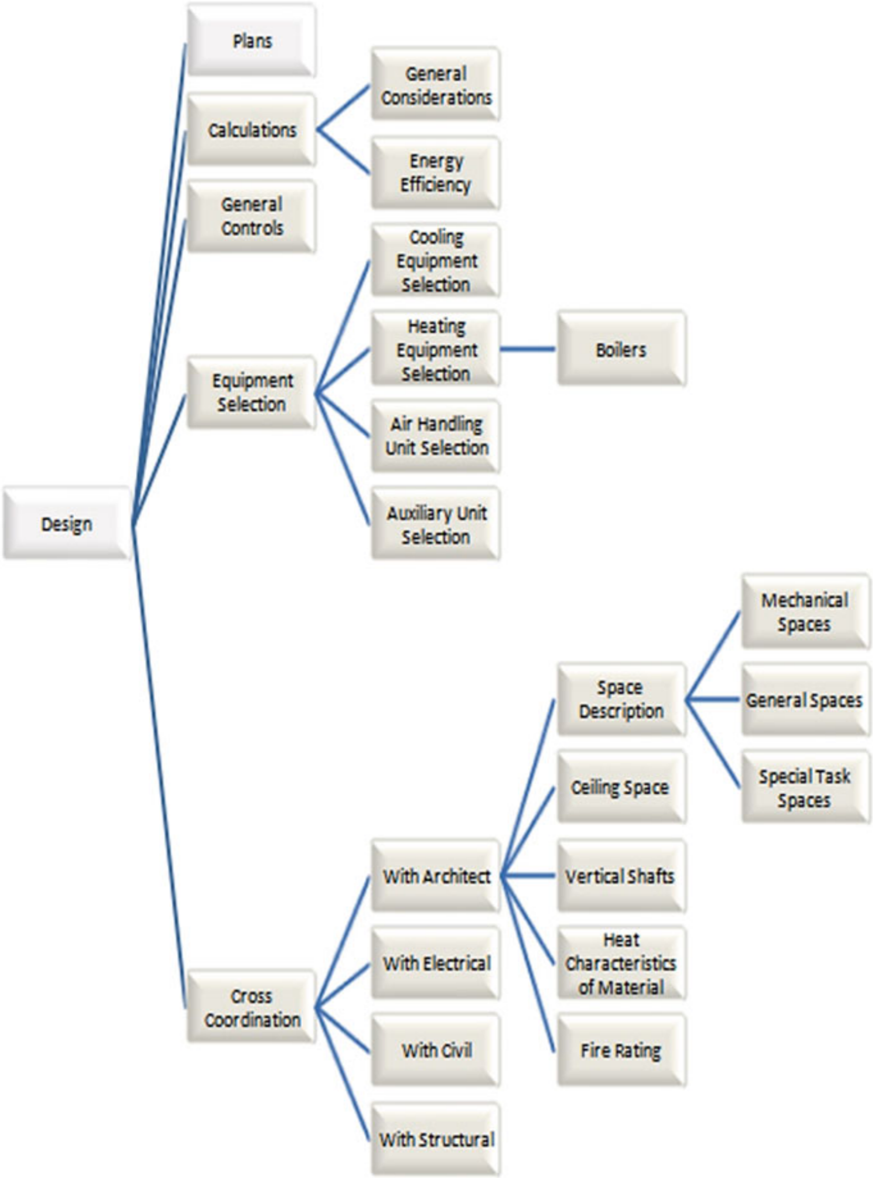

Fig. 3.2 HVAC engineer design responsibilities

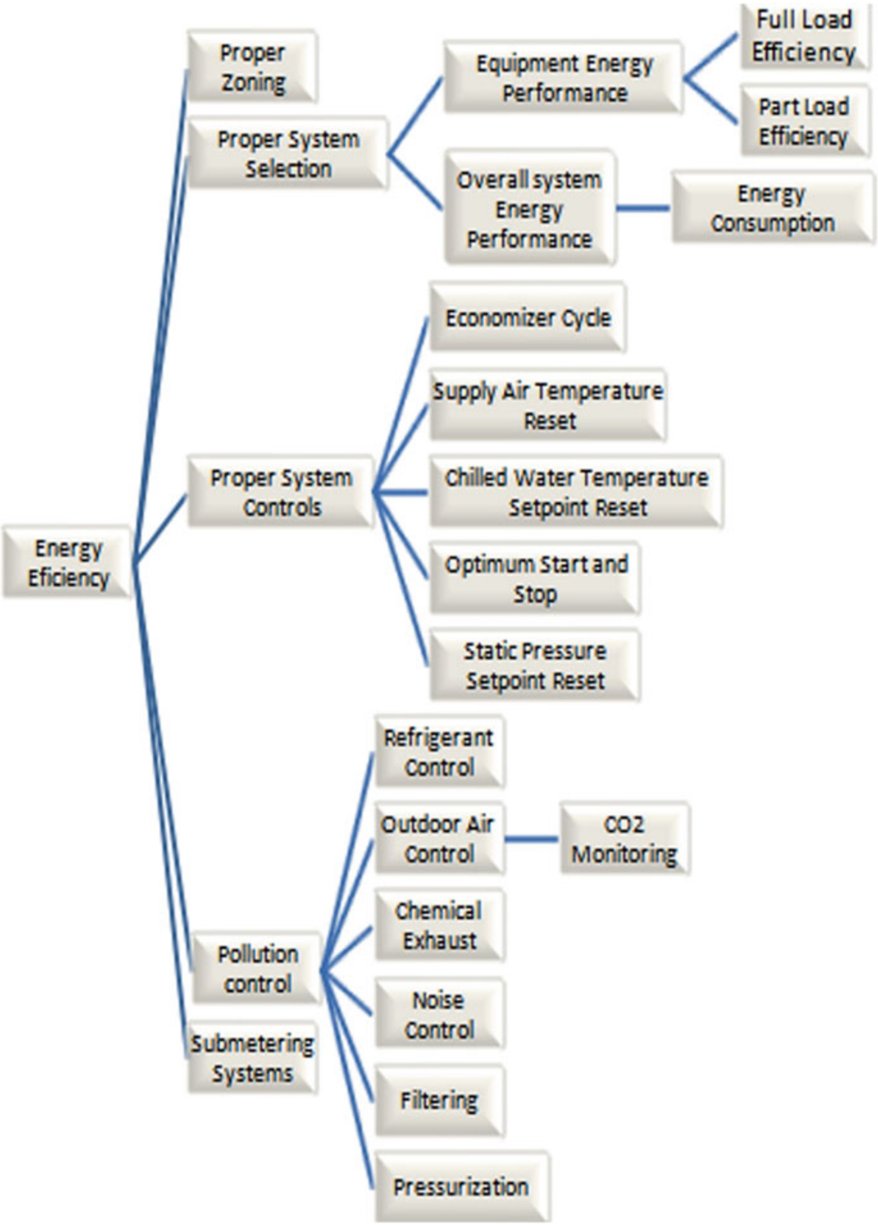

Fig. 3.3 HVAC energy efficiency design considerations

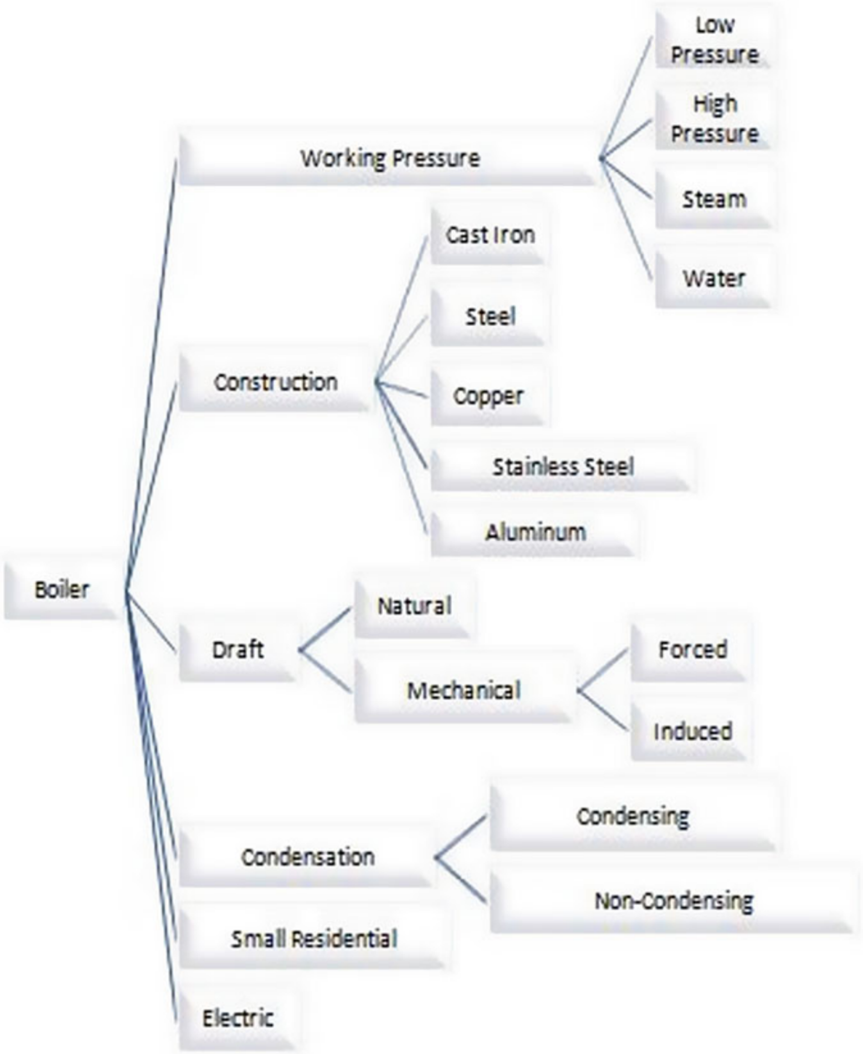

Fig. 3.4 Boiler selection

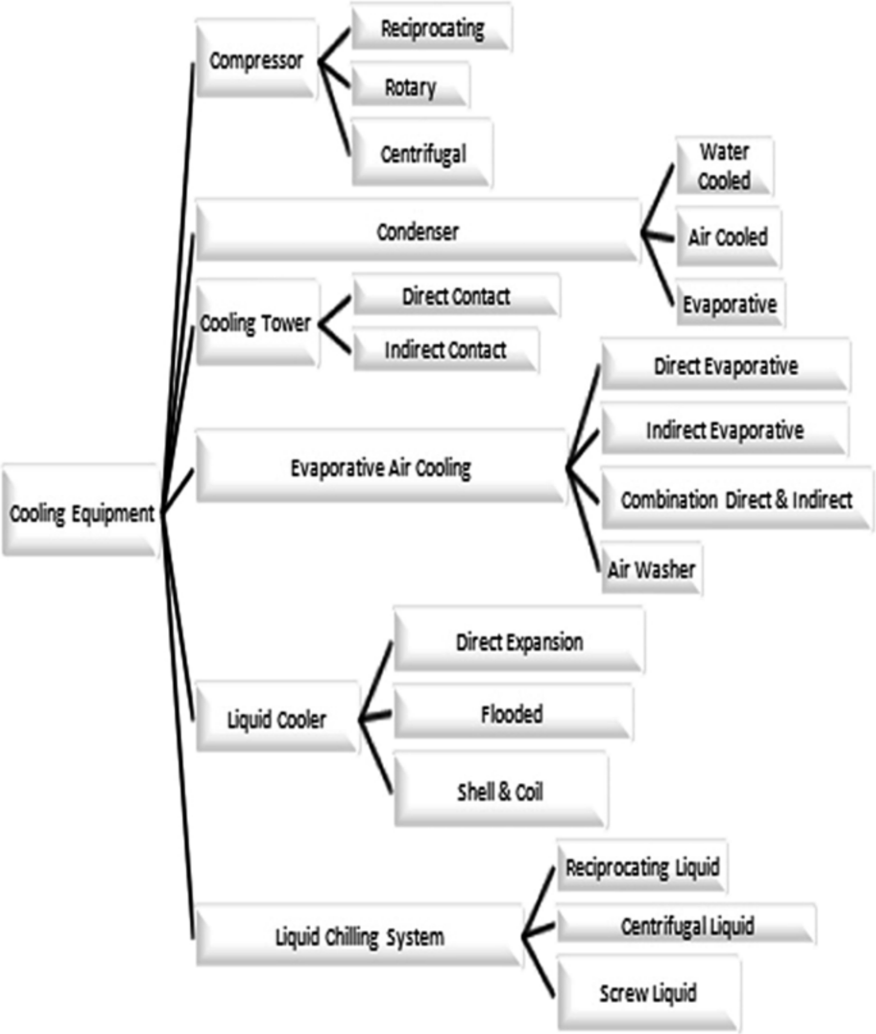

Fig. 3.5 Cooling equipment selection

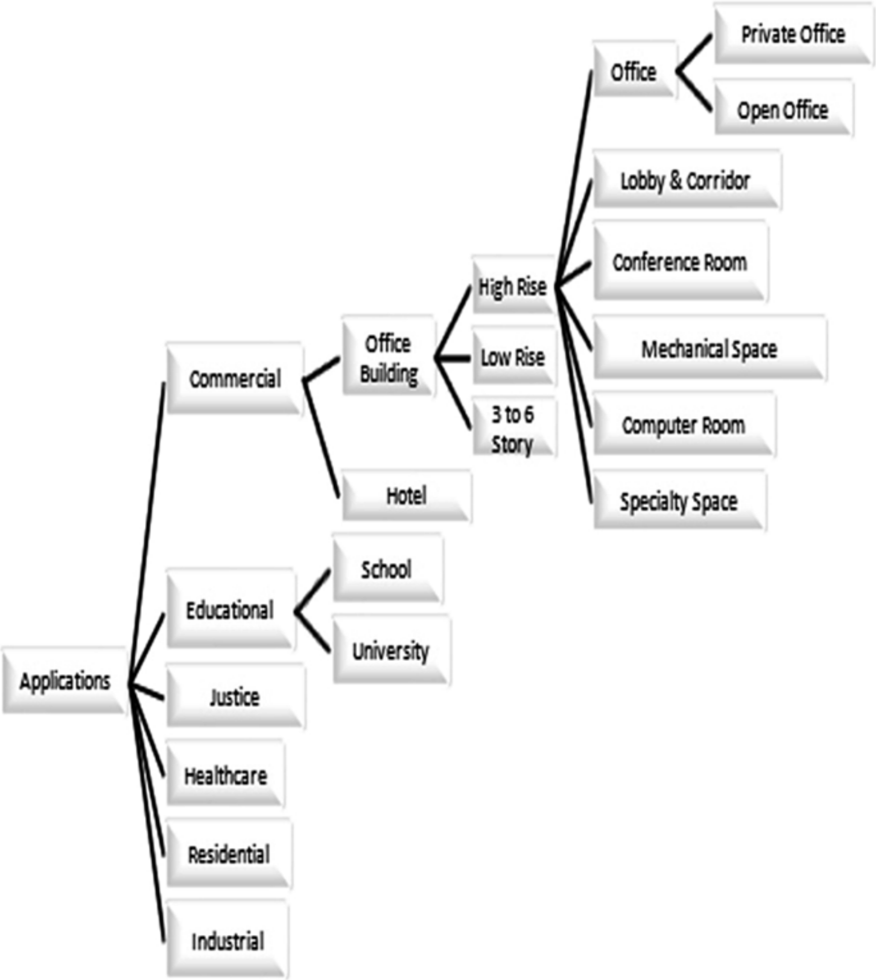

Fig. 3.6 Building applications

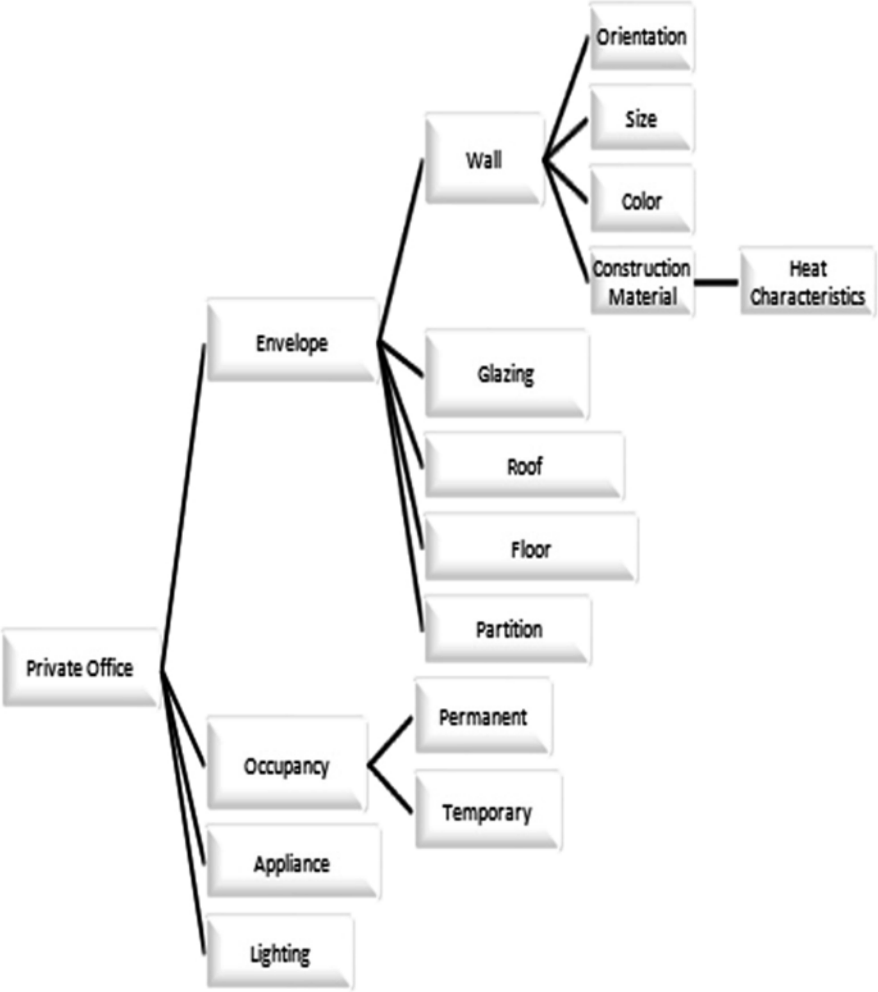

Fig. 3.7 Private office characteristics

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Part III
Frameworks and Standards

Chapter 4
Frequently Used Codes and Standards

The Merriam-Webster dictionary definition of "Code" is a systematic statement of a body of law, specially one given statutory force, and "Standard" is something established by authority, custom, or general consent as a model or an example. In general, engineering codes (absolutely to be followed) and standards (to be followed as a good engineering practice) are developed to hold the design and construction industry players responsible to a minimum acceptable level of designing, constructing, manufacturing, commissioning, controlling, testing, etc. There are a large number of regulatory codes, guidelines, and standards which direct the design and construction community members to the correct way of performing their duties. These regulations cover all the aspects of the design and construction and its prime target is to protect the occupants, buildings and of course the environment. In general for the design and construction environment from the point of view of an HVAC engineer or contractor the mechanical, building and energy codes, ASHRAE standards and testing agencies regulations are the most important reference documents to be followed.

Codes are usually being updated every few years and cover the general and overall building design and construction requirements, and its electrical, mechanical, energy, etc. issues. Different ASHRAE standards that are also being updated every few years cover almost all aspects of the building HVAC design and construction and also some other energy related issues. Even though these codes and standards and also other important similar documents usually discuss every aspects of the building, its systems, its environment and its occupants, here similar to the flow of the rest of this book, I only emphasize on HVAC and energy related contexts of these guidelines.

Generally the mechanical codes have been written to provide guidelines for the design and installation of mechanical appliances and systems, such as venting, exhausting, ductwork, piping, and also refrigerant systems. Proper installation location and required access for the appliances and mechanical systems are also discussed in mechanical codes. The mechanical codes describe how the venting, exhausting, and ductwork systems should be designed and installed to control

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temperature, humidity, and air contamination of the building, along with means to protect both structural elements and equipment integrity and occupant safety (such as fire safety system) through proper air delivery, ventilation, and exhaust systems.

It should be noted that the mechanical engineer should also familiarize himself with the other general building codes as well. These codes are mostly concerned with the building architectural requirements. Of course these architectural regulations and requirements sometimes play a decisive role in decision making of the mechanical engineer in his pursue of mechanical design. Among others, the main topics discussed in building codes are building use and occupancy classifications and requirements, limitations in height and area of the construction, fire resistance and fire protection requirements, and safeguarding during the construction.

The energy conservation codes are generally design guidelines which depict the regulations and requirements for designing a building with minimum acceptable energy efficiency provisions. One of these standards (ICC 2012b) allows for either prescriptive or performance-based approaches. The guidelines usually at the beginning of the building design process require the designer—based on the applicable conditions—to use these codes to select and specify design parameters such as minimum acceptable thermal characteristics of the building envelope components, minimum efficiency for the mechanical equipment, minimum lighting and power efficiency, and duct and pipe insulation characteristics.

In addition to the overall mechanical and building codes, which international codes (ICC 2012a, c) written by the council of international codes are the most commonly used among them, other agencies or societies such as ASHRAE has developed additional specific standards and guidelines in order to make the design and construction process even more clear, straightforward, and safe. For example one of these standards ASHRAE standard 15 (ASHRAE 2010a) is developed to depict a safe framework for designing, construction, installation, testing, inspection, and operation of mechanical system that are working based on utilization of a refrigerant cycle. This has been proven that different refrigerants represent big danger for people and environment safety specifically when there is a path of leakage of these agents out of a refrigerant machine. Therefore the refrigerant leakage from refrigerant machines should be monitored and means for alarming, identifying and correcting these incidents should be developed clearly. This standard in addition to representing the classification of the refrigerant systems also focuses on means of people, building, and environment safety in regard to the danger of refrigerant chemical characteristics.

Providing a building with high indoor air quality is one of the most important aspects of a high performance building design and operation. Indoor air quality has a direct effect on health, comfort, and productivity of the occupants. The main target of ASHRAE standards 55 (ASHRAE 2010b) is to define the thermal conditions under that the majority of the occupants who are living and working in that building feel comfortable. In achieving this target, the standard requires designing with multiple indoor environmental factors and of course personal factors in mind. According to related literatures, a complete and meaningful thermal comfort design cannot be achieved without addressing metabolic rate, clothing insulation, operative temperature (a temperature that is calculated based on air temperature and mean radiant temperature), air speed, and humidity. Therefore this standard defines these factors and represents a method for determining acceptable comfort condition in occupied spaces based on a combination of all these factors. In this method operative temperature, provisions for humidity control, elevated air speed, air speed measurement, temperature variations with time, and local thermal discomfort such as radiant temperature asymmetry, draft, vertical air temperature difference, and floor surface temperature have been discussed as well. Two graphical and computer-based calculations have been represented to define predicted mean vote (PMV) and predicted percentage of dissatisfied (PPD) people based on the comfort factors that have been described earlier.

A separate section is dedicated to the method of determining comfort in spaces that are using natural ventilation with use of operable windows.

Complying with this standard is a major part of any sustainability scoring system in forms of design, controllability and verification of occupant's comfort. This standard originally published in 1966 and it has been repeatedly updated and republished since then.

Outdoor air conditioning is one of the most important and also energy-demanding parameters in building load calculations, and therefore energy consumptions. The more extreme the outdoor conditions in heating and cooling seasons are, the higher is the required energy for conditioning the outdoor air to a proper level that is suitable for using inside the building. The main purpose of ASHRAE standards 62 (ASHRAE 2013a) in addition to definition of the different air classes is to make sure the minimum acceptable air quality for the occupants in a building is provided. In order to guaranty this condition, the standard specifies the minimum required outdoor air rate for each space. To specify this rate the standard offers two different methods of ventilation rate (VR) procedure and indoor air quality (IAQ) Procedure.

Outdoor air quantity based on ventilation rate procedure method is a prescriptive procedure and is calculated not only based on the type of the application and space area, but also based on the number of people in the space. In this standard the method of calculation for the proper outdoor air quantity for different spaces, applications and density of expected people are discussed. The standard recommends a combination of floor space and people density calculation for every single space in the building. As an example the standard recommends 0.06 cfm outdoor air per each square foot of office space plus 5 cfm outdoor air for each person expected to work in this office. Therefore for an office with 200 square foot floor space which is designed to provide working space for two people the total outdoor air requirement will be 22 cfm. This quantity of outdoor air should be introduced to the office space at all time. These calculations should be done for every single space located in the part of the building that is being served by a single air handling unit, and at the end the whole quantity of outdoor air for all the spaces should be adjusted in regards to the most critical space in the system, in order to make sure that all the spaces in this system receive proper outdoor air quantity.

On other hand IAQ is a performance-based design procedure offered by the standard as an alternative in which outdoor air intake rates and other system design parameters are designed to maintain the concentrations of specific contaminants at or below certain limits.

The main purpose of another one of ASHRAE standards, ASHRAE 90.1 (ASHRAE 2013b) which probably is the most important standard that depicts the requirements for an energy efficient building design is to establish the minimum energy efficiency requirements of buildings for design, construction, and a plan for operation and maintenance and utilization of on-site, renewable energy resources. The early versions of the standard were published in 1975 and since then it has been updated regularly. To comply with the requirements of this standard the building shall comply with requirements depicted for Building Envelope, Heating, Ventilating, and Air Conditioning, Service Water Heating, Power, Lighting and Other Equipment in a prescriptive line-by-line method. As an alternative two methods of performance-based energy simulation are represented, which complying with one allows for standard compliance, and exceeding the limits depicted by the other method allows for rating the building in sustainability scoring systems.

On the other hand AHRI standards are a group of standards developed by the American Heating and Refrigeration Institute to establish testing, rating, and minimum data requirement for different HVAC equipment. These standards are intended to provide guidance for the industry players in order to make them capable of recognizing and relying on the published data about efficiency of the equipment. One of the valuable information in these standards is the allowable test tolerance of the equipment when it undergoes the proposed testing procedure for its efficiency to be evaluated. This is proved to be a vital information for risk based decision making where we will discuss it in the final chapter of this book.

For a comprehensive list of AHRI standards refer to http://www.ahrinet.org/standards.aspx web site. Some of the most common AHRI standards are standard 310 (ANSI/AHRI/CSA 310/380-2004) that targets the packaged terminal air-conditioners and heat pumps and its performance testing requirements, standard 430 (ANSI/AHRI 430-2009) that targets central station air handling units and its performance testing requirements, standard 440 (ANSI/AHRI 440-2008) that targets room fan-coils performance testing requirements, and standard 550 (AHRI Standard 550/590 (I-P), 2011) that targets water-chilling and heat pump water-heating packages using the vapor compression cycle and its performance testing requirements.

Standard 340 (ANSI/AHRI 340/360-2007 with Addendum 2) and standard 365 (ANSI/AHRI 365 (I-P)-2009) target commercial and industrial unitary air-conditioning and heat pump equipment, and commercial and industrial unitary air-conditioning condensing units, respectively, are also among the most useful standards in this group.

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Chapter 5
Performance-Based Standards

A building is made of numerous constructing elements. Each of these elements not only is affected by and has to face the enforced pressure from the other building elements, but also has to resist the effects of the environments (both inside and outdoor). The behavior of these elements when they are facing a combination of these factors simultaneously defines the element performance.

A performance-based standard or code is mainly focused on the outcome and result of a procedure, product or service and pays either no or at best just a minimum attention to the how about of the procedures which leads to achieving this outcome. While a prescriptive standard or code concentrates on detail steps that should be taken to provide the acceptable products or services as defined by that standard or code.

An example of a prescriptive code statement which is the language of the majority of the current codes and standards can be stated like this: "Provide twenty cubic foot per minute per person (20 cfm/person) outdoor air for the building." This means that the code writers have confidence that in order to have proper outdoor air ventilation capacity for a building, it is enough to provide 20 cfm of outdoor air for each occupant in the building and this quantity of outdoor air can satisfy all the needs for a clean and healthy indoor environment. While an example of a performance-based code regarding the same issue can be stated as: "Provide sufficient outdoor air for the building to establish a healthy and comfortable environment for the people staying and functioning in the building. Calculated and distributed enough fresh air to the spaces based on the space need and usage. Provide monitoring, measuring, delivering and balancing devices for introducing fresh air close to level of breathing of people with no short circuiting of the outdoor air through return or exhaust devices. Ventilation system shall remove all the pollutants from the room." Of course at first glance the prescriptive method seems very direct and clear to follow, but as I stated earlier the performance-based method can invite new invention and advancement in the industry due to allowance for designers to come up with innovations and newer methods to fulfill the design purpose.

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In some standards a mix approach of part performance, part prescription has been adopted. The more dominated the performance section of a standard or code is the designer has more freedom in specifying newer products and solutions. For an involved person in any aspect of the building industry design and construction it is essential to understand and be capable to execute his duties based on either one of these methods. Of course we all are fairly familiar with language and structure of prescriptive codes and standards due to our interaction with such languages through our daily lives, and there is no need for further explanation here about how these statements are being written. On the other hand I feel the need for a more comprehensive explanation for the performance-based method that just recently has gained some momentum in the industry code writing environment, even though in other parts of the world they have been using such standards for a while.

In order to describe the required performances and achievement targets by a performance-based standard or code the most important steps are to (1) describe things in a supply and demand language and (2) develop and compare quantifiable performance indicators (PIs) and key performance indicators (KPIs).

Demand and supply languages are generally referred to the vocabulary that is being used to describe the required functions and performances of the object or service intended by the user, and the technical and performance specifications represented by the technical team, respectively. In other word the demand language is the way that owner or user explains what he needs and supply language is the way that technical team uses to define and express the performance of the solution presented to the user or owner to fulfill his needs.

The second necessary step in developing a performance-based standard is developing performance indicators which will act as the representatives of the effects of the important factors in a process or product.

To simplify understanding of this concept let's assume a group of researchers are working to generate a performance indicator representing the level of comfort of occupants in a building. Obviously the first issue that they have to take on is to specify all the major influential factors (systems) on the comfort level of the occupant in the building. The next step then should be to separate the most important systems from those with negligible or little effects based on the available data from the existing literatures or through an expert judgment procedure. The following step then should be to define a mathematical structure for the indicator as a function of the selected important systems. In our example assume the researchers have selected environment system and individual system as the two main important systems to develop a good performance indicator for the building occupants comfort level. Therefore they decide to describe the comfort performance indicator as follows:

$$\mathrm{PI}(\text{Occupant comfort level}) = f(\text{Environment system, Human system}) \tag{5.1}$$

The next step is to describe the two main systems based on their important subsystems. This once again could be done based on relevant literature review or expert input and can be described as follows:

$$\text{Environment system} = \psi\left(T, H, \mathrm{AD}, \mathrm{AV}, \mathrm{HV}, L, O\right) \tag{5.2}$$

and:

$$\text{Human system} = \varphi\left(G, M, F, C\right) \tag{5.3}$$

with:

"T" representing temperature
"H" representing humidity
"AD" representing air direction
"AV" representing air velocity
"HV" representing heating, ventilating, and air conditioning System
"L" representing lighting system
"O" representing space exterior exposure and orientation system
"M" representing metabolism
"G" representing gender
"F" representing function

and finally:

"C" representing clothing

Obviously the next step will be to designate a weighting value to each of these parameters, which could again come from literature, expert input, multiple experiments and actual field data, calculations or even owners emphasize on a specific need for his project. By working through the above-explained steps, finally the performance indicator could be expressed as follows, as a function (β) of these multiple factors:

$$\text{PI}\left(\text{Occupant comfort level}\right) = \beta\begin{bmatrix}(a\times T),(b\times H),(c\times \text{AD}),(d\times \text{AV}),\\ (e\times G),(f\times F),(g\times M),(h\times C),\\ (i\times HV),(j\times L),(k\times O)\end{bmatrix} \tag{5.4}$$

With multipliers "a" to "k" each represents the overall weight of each factor for constructing the targeted performance indicator. After setting up the proper formulation for each of these subsystems, the overall PI shall be verified and adjusted based on actual tested data. Only then we can have a legitimate PI describing the human comfort condition.

After establishing such a formula for this specific PI, a specific value then could be generated for this PI for any given condition. Now by calculating PIs for each condition and comparing the generated PIs for each of these conditions, the performance of different systems in relation to each other can be determined.

Even though for different specific purposes different PIs can be generated, but usually there is one PI which has the highest importance from a specific point of the view such as the owner's perspective, designer's perspective, etc. This performance indicator is known as the key performance indicator (KPI) which usually includes the most important parameters and their relative weights from that specific point of view. This KPI can be used to set the main design achieving goal(s).

Let's look at another example. One of the most popular key performance indicators in building design and construction industry is building energy consumption per square foot per year. If we look and see how this KPI has been developed we can see the typical pattern that has to be followed to generate any (key) performance indicator in general, and also realize that it is not a simple task to create such valuable tools. As it was said earlier, the first step is to define the main systems that contribute to generating this indicator. Therefore this KPI can originally be defined as follows:

KPI (Energy Consumption per square foot per year) = ω (Envelope system, HVAC system, Hot water system, Electrical system, Miscellaneous system)

Likewise each of the developing systems should be defined by its own subsystems such as:

Envelope system = τ (floor system, exterior wall system, roof system, partition system, location, and orientation system, glazing system, etc.)

Furthermore each subsystem has its own subsystems, such as:

Exterior wall system = τ_1 (wall orientation system, wall net area system, wall construction type system, etc.)

And even more:

Wall construction type system = τ_2 (wall heating characteristics system, wall coloring system, etc.)

Therefore it can be seen that a thorough and detail formulization should be utilized to enable us to use all these systems and subsystems to calculate the amount of heat loss or heat gain of the building throughout the year just for the envelope system. The total heat loss or gain of this system then should be used as one of the subsystems of HVAC system along with HVAC system's other subsystems. All these information shall be combined in an energy modeling type approach to sum up the final function representing the building energy consumption per square foot per year or the targeted KPI. When that overall formulas developed, adjusted and its accuracy verified then it can be used to calculate any other building KPI for comparison among the different buildings energy consumption.

As the third example, in the following illustrations typical procedure that can be followed for developing different performance indicators for day-lighting system for a building are shown. Figure 5.1 shows the logic to be followed for developing demand and supply language for the targeted outcomes. In the demand (functional) side of this simplified chart the targeted performance desired by the owner or user has specified as "Provide a better indoor environment" and is shown on the top of the chart and sublevels in order to provide this functionality have been developed level by level below that. In the final sublevel and just above the possible performance indicator the "Day-lighting System" function is positioned, which is the main target of this exercise.

Meanwhile on the technical system side, influential systems that could have significant effect on realization of the targeted performance have been written and

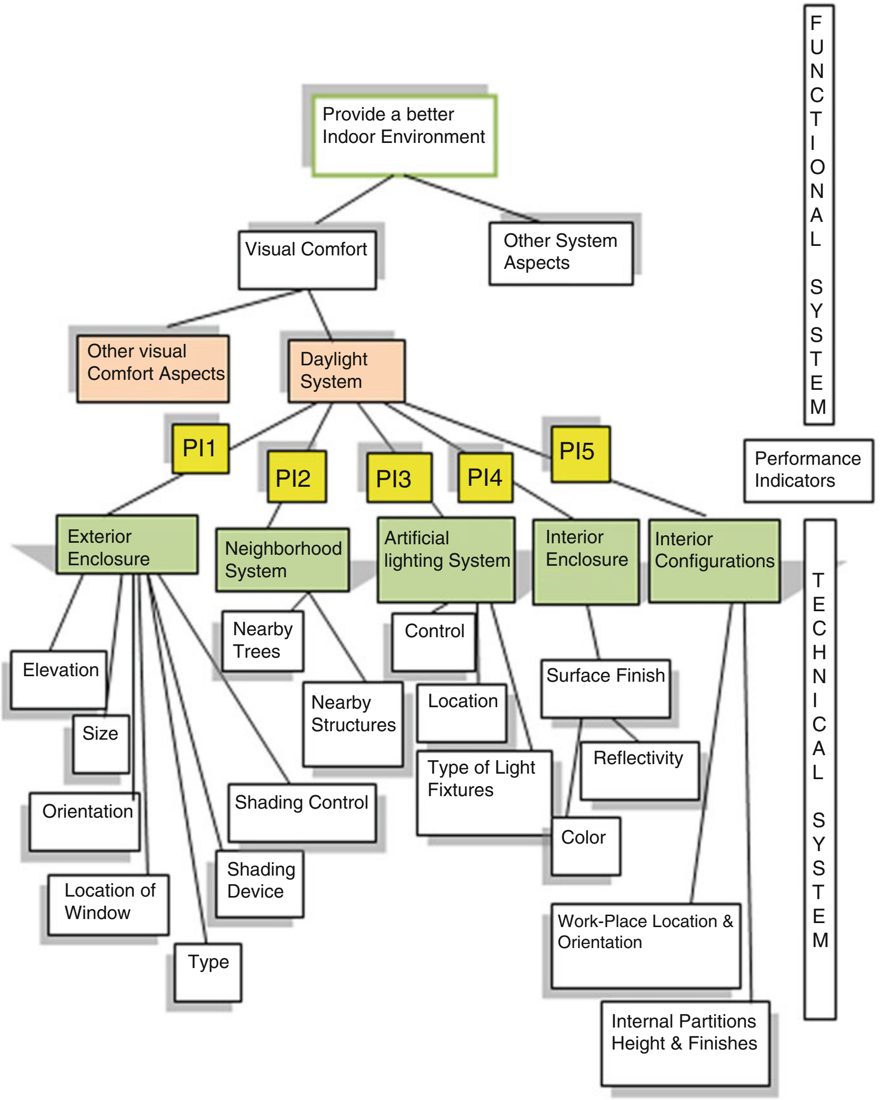

Fig. 5.1 Option 1 of demand and supply chart

each technical system has been related to the factors which have direct effect on how the specific technical system can perform.

It can be seen that a few good performance indicators can be developed to represent the “Day-light System.” For example PI3 relates the “Day-light System” to the building artificial lighting system. It could be easily understood that “Day-light System” can somehow be expressed by PI3 based on the weighted factors of controls, type and location of the light fixtures. Also PI1 relates the “Day-light

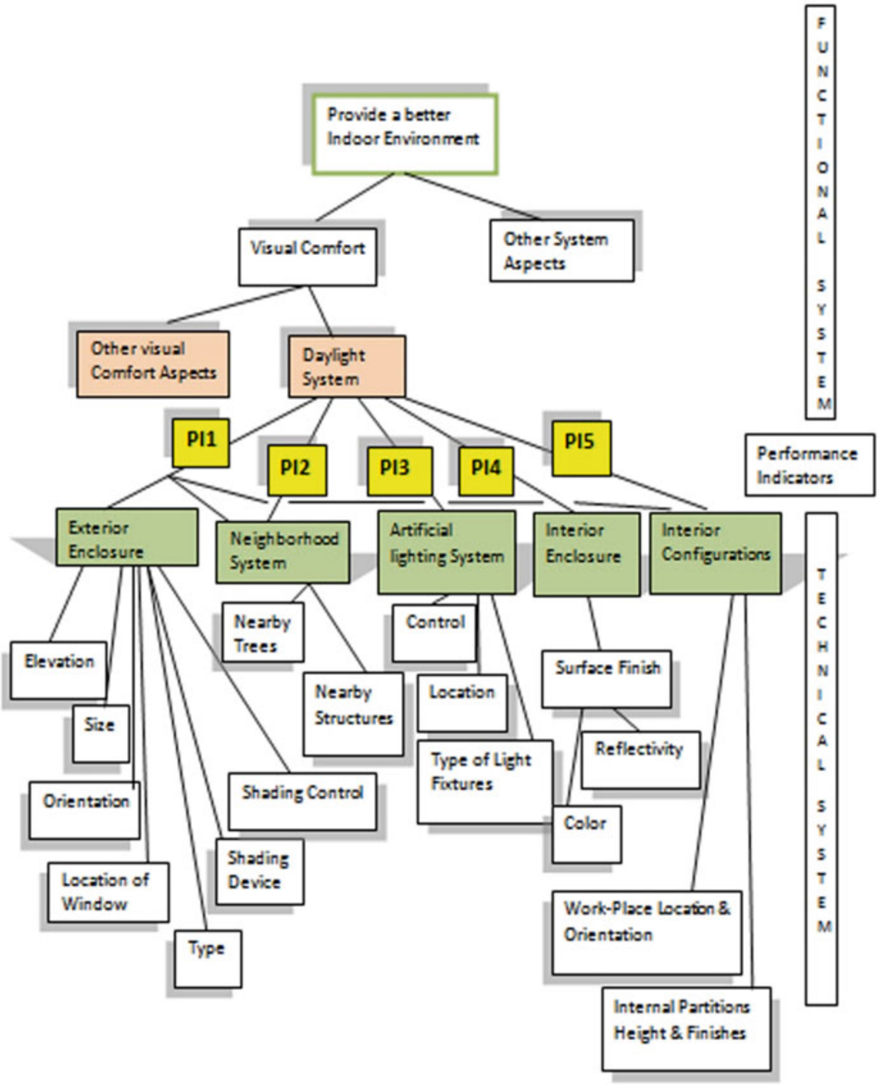

Fig. 5.2 Option 2 of demand and supply chart

System" to the building external enclosure system as well. It could be easily understood "Day-light System" can somehow be expressed by PI1 based on the weighted factors of elevation, size, orientation, location, shading device type, and controls.

More complex performance indicators can be developed by relating more technical systems to one performance indicator for expressing one functional system as it has been shown in Fig. 5.2.

Here PI1 has been used to relate "Day-light System" to three technical systems at once. These systems are exterior enclosure, neighborhood system, and interior configurations systems. It could be easily understood “Day-light System” can somehow be expressed by PI1 based on the weighted factors of elevation, size, orientation, location, shading device type and controls, nearby trees, nearby structures, work-place location and orientation, and internal partition height and finishes in a manner that was explained earlier in this section.

Other than energy consumption per year per square foot of area that is one of the most important performance indicators in energy modeling, other performance indicators can also be developed to target improving the overall energy efficiency of the building and its systems. As we said earlier some aspects of the design cannot be fed to the current general energy modeling software, for example there is no place for evaluating the external noise effects on overall energy consumption of the system. Should we forget this effect, or noise even has any effect at all on the energy consumption of the building. Let’s assume we have a building that is designed with a combination of mechanical and natural ventilation systems. Anytime the outdoor conditions are favorable system switches to natural ventilation mode, and when the outdoor conditions are not preferable system switches to mechanical ventilation mode. Of course natural ventilation mode operation relies on the windows to open and allow free outdoor air circulation in the building. Existence of external noise, on the other hand, would limit this favorable mode change and will probably force the system to run on its mechanical mode more frequently, because people do not desire to work or live in a building while they are exposed to undesirable high external noise levels. That of course can be translated to more energy consumption, even when there are favorable outdoor conditions. This shows that external noise can be a factor that affects the building energy consumption. The best way to include this factor in our system design and evaluation therefore is to generate external noise performance indicators, which needs to be investigated and developed based on the noise calculation equations, relative distance of the buildings to sources of external noise, etc. as a benchmark for any other building. This performance indicator in addition to general energy consumption per year per square foot of the building should also be met or be exceeded from during the design for a building to be tagged as energy efficient building.

As an example of a complete performance-based standard, Qatar sustainability assessment system (QSAS) is a custom-made sustainability assessment system designed for the state of Qatar. This system was designed by TC Chan center of University of Pennsylvania. QSAS is a perfect example of using multiple PIs in developing a performance-based standard. In this standard for different categories of design, construction, and operation, different PIs have been calculated and have been set as the comparison baseline values that any proposed building in the state of Qatar has to be evaluated against before being constructed. To make a better understanding of how such systems work let’s look at one of the required performances and explain how the building has to comply with this requirement.

In order to develop such performance based standard, one needs to develop multiple PIs to cover the whole required energy aspects of the building by the standard. For example assume you want to develop the performance indicator for “use of natural ventilation” in the proposed building. At first you have to calculate the building usage of natural ventilation during the year. This can be done based on the available equations, normally should be provided in the standard. The calculated value of use of natural ventilation then should be evaluated against a set of values, e.g., from zero to better than three. If based on the presented calculations there is no possibility for the design building to utilize the natural ventilation mode during the year, the score will be zero, and if the calculations show there is a possibility of one ($PI_{NV} = 1$), two ($PI_{NV} = 2$), three or more ($PI_{NV} = 3$) months in the year for utilizing natural ventilation in lieu of mechanical ventilation then the proposed building scores 1, 2, or 3 points for this PI_{NV}. Building shall undergo all the different evaluating PIs, and the combination of all the PIs represents the final score and shows the building level of sustainability.

As a final note it should be said that one of the areas that most of the designers hesitate to design and the code officials hesitate to accept performance based design instead of prescriptive design is the fire protection systems in the building. It is of course because the fire protection system has a direct effect on the life and safety of the building occupants in case of breaking fire in the building, and therefore following the exact prescriptive guidelines are almost always preferred. For an in depth discussion on performance based buildings see (Augenbroe 2011).

Reference

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Chapter 6
Indoor Air Quality

6.1 Main Sources of Problem

Having a high-quality indoor air is one of the most important factors in defining the quality of any building. People's wellness and productivity have a direct relationship with how well indoor air of the building that they live and work in has been designed and maintained. Since people live and function inside the buildings and along with the operating equipment and appliance in the building contribute to the age and lack of freshness of the air inside the building, a continuous introduction of proper amount of fresh air into the building is a vital factor in keeping a high-quality indoor air condition.

Quantity of the fresh air inside the building has been the subject of many discussions and has been continuously revised by the governing standards such as ASHRAE standard (ASHRAE 2013) through the years. In order to design and maintain a building with a high-quality indoor air, designers should comply with the recommendations specified in these standards. This requires specific calculations, implementation provisions, monitoring, and verifying the contributing factors to air quality. The current standard requires enough fresh air equal to result of a function developed based on combination of number of people who are living and working in each space and the total space area. The standard requires some correction in order to increase the calculated required fresh air in order to compensate for every area in receiving the minimum required calculated outdoor air. Since in mixing air handling units, space return air will be mixed with outside air before discharging into each space, basically even with these corrections there is no guarantee that every single space receives the proper and calculated quantity of outdoor air. Therefore some rooms may receive more than adequate, and some rooms may do not receive enough outdoor air at all. As a result the best way to make sure all rooms will receive proper quantity of outdoor air the best bet is to utilize dedicated outdoor air units that deliver full outdoor air requirement of each space directly to that space.

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As it can be seen, the delivered air to the building through an air conditioning system should not only be capable of providing the needed cooling, humidification, dehumidification, and heating for the purpose of creating a functional and comfortable environment for the building occupants but also should be clean and healthy and have a high quality to protect the occupants against possible health-threatening issues created by substandard air quality as well.

Other than the outdoor air that enters to the building through the air-handling units, more outdoor air can find its way into the building through other sources such as cracks and openings. Among many other contributing factors to a lower quality air inside the building uncontrolled moisture and contamination need special attention, and proper means for controlling the sources of these problems in the building shall be designed and planned in order to make sure that a building with a minimum acceptable indoor air quality is constructed and could be maintained.

Keeping the humidity of the building within an acceptable range has been defined by different standards and literatures and is an essential source of people's comfort and health, and also building functionality. Any additional humidity beyond this recommended levels, is unwanted moisture. Unwanted moisture inside the building can be the result of the moisture penetration through the building envelope, condensation of water vapor over the interior building cold surfaces, improper pressure relation design of the building in respect to the outdoor, etc. Condensate generated over the cooling coil within the air handling unit and the water that is used for watering indoor plants and decorative water features are examples of the other sources that can contribute to accumulation of unwanted moisture inside the building. The excessive indoor moisture generated by any of these sources, can cause undesirable conditions such as building surface mold, uncomfortable condition and even occupant sickness. On the other hand excessively less moisture than what is recommended by the related standards can easily decrease people's level of comfort as well.

Similarly, the contamination inside a building can be the result of introduction of low quality outdoor air, lack of proper exhaust from the building, and lack of proper air balance in the building, etc.

Obviously, understanding the nature of these problems and of course finding proper methods of preventing the occurrence of these problems are essential factors for providing a building with high indoor air quality. In the rest of this chapter I will discuss common moisture and contaminants issues and also methods of preventing the complications that could be created by them in more detail.

6.2 Moisture Control

Proper moisture content in the building indoor air has a significant effect not only on the level of comfort of the building occupants, but also on protecting vulnerable material which are sensible to the indoor air humidity level, such as books in libraries and art works in museums. Experience has shown a relative humidity of 45–55 % is considered to be the proper level of humidity in most applications, while this range can be expanded on either side by a few percentages for less critical applications. Therefore designers should employ means of air humidification or dehumidification to keep the total indoor air relative humidity within these limits throughout the year.

To achieve this goal the obvious first and most important step is to limit entrance of excessive amount of outdoor unwanted moisture to the building through cracks, building joints and openings. This goal simply can be achieved by employing high quality workmanship in construction phase of the building and also by installing suitable vapor barriers on the building envelope exterior surfaces. Proper architectural designs such as utilizing revolving doors or vestibules can also contribute to the elimination of the building interior environment contact with the outdoor through direct openings. It should be noted that cracks and openings can be a source of infiltration of pollutants and even bacteria into the building as well.

Three major contributing sources of entrance of unwanted moisture (and also pollutant) into the building via infiltration through the cracks and joints are known to be wind pressure, stack effects, and improper pressure balance in the building.

One of the most effective methods of preventing the outdoor air moisture and pollutant to enter the building is designing a mechanical pressure system utilizing a fan that continuously monitor the outdoor air pressure and keeps the building under positive air pressure relative to the building outdoor condition. The only negative outcome of this method is its need for extra indoor air quantities over what it is really needed for people comfort. Therefore additional conditioned air, which can be translated to additional energy consumption, should be generated and delivered to the space.

A poor air handling unit design, installation and maintenance or lack of proper draining of the condensate water generated at the cooling coils is another path for allowing unwanted moisture into the ducts and building. When the velocity of the air that is moving over the cooling coil reaches or moves above a proper level (usually above five hundred foot per minute (500 fpm)), it creates an opportunity for some of the moisture in the air stream to pass over the coil without proper contact with the coil surface and therefore leave the coil section without draining all of its moisture content in the drain pan. The moisture left in air stream then will be carried on to the ductwork or inside the building and will become the source of unwanted conditions such as uncomfortable environment or even creation of mold. The most common way to prevent this condition is to design a large enough contact surface for the cooling coil to minimize the maximum velocity of air over the coil to not more than 500 fpm.

After all means of preventing entrance of unwanted moisture to the building is provided an easier follow-up task then would be to control the humidity that is generated inside the building. This humidity can be generated from the daily building functions and occupant activities. A well designed cooling and dehumidification system can provide proper humidity level inside the building during the summer. In winter time however a well-designed heating and humidification system can maintain the indoor humidity above a minimum proper level.

A common method of dehumidification of the delivered air to the space through air conditioning system is cooling and then reheating the air before introduction to the space. This helps to remove the excess humidity out of the air stream that is cooled down close to saturated level, but due to the fact that simultaneously cooling and heating the same stream of air is not energy efficient, its usage have been limited by the governing standards. Another more accepted way is reducing the humidity in the outdoor air stream by using energy recovery units. In these units a wheel equipped with some kind of moisture absorbent is used to not only remove the excess moisture from the air stream before delivering it to air handling unit, but also to transfer the heat that is usually wasted via exhaust air streams to the outside air and therefore economically preheat this air, where it is applicable.

6.3 Contamination Control

The outdoor environment can be source of a wide verity of contaminants such as nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), airborne dust, airborne volatile organic compounds (VOCs), and airborne odors. When we are designing a building, the existence of these contaminants in outdoor air shall be recognized and their contamination levels shall be closely monitored and controlled. Contamination can be reduced with proper contamination reduction methods before the outdoor air is introduced to the air system of the building via intake air louvers, hoods, or any other means of introduction of fresh air to the building. Environment Protection Agency (EPA) has developed the National Ambient Air Quality Standards (NAAQS) in which, the level of pollution of different areas in the USA in regard to different pollution agents are specified. These guides specify the areas in the country that the building indoor has to be protected against specific regional outdoor pollutions. For example if NAAQS specifies an area as nonattainment for sulfur dioxide (SO_2) pollution, then the HVAC design team in addition to the other general building ventilation requirements, such as minimum required outdoor air regulated under relevant standards, shall specify specific provisions such as gas-phase air cleaner as part of their design in order to resolve this specific region related contamination problem as well. It should be noted that the EPA provides both primary (to protect human health) and secondary (to protect environment) attainment requirements to be complied with.

As it was said earlier, similar to moisture, contamination can enter the building from different sources. For example in locations where the outdoor air contamination level is high and a proper air pressure relation between the contaminant area and the building is not maintained, contaminants can find their way into the building through cracks or open windows. Also lack of proper design or operation of the air handling unit air filtration could be a resource of entrance of contamination to the building. That implies that the first step in controlling level of contamination inside the building obviously is selecting the proper geographic location and climatic condition (wind) orientation for the building. By selecting locations that the outdoor environment is not contaminated or by orienting the building air intakes in such manner that they are not faced with the direction of prevailing wind carrying contaminations this target could be achieved.

The next step towards protecting the building against entrance of contaminants is using high quality filters on air handling units which are serving as the outdoor air providers to the building. These filters are usually specified by their Minimum Efficiency Reporting Value (MERV) which is a value between 1 and 20 and the filter efficiency and collection capacity increases as the MERV number increases.

Furthermore providing sufficient exhaust from interior spaces with high levels of pollution or undesired chemical elements and keeping the proper relative pressure between these spaces and the rest of the building is very important to create a pollution-free space inside the building. For a detail discussion on indoor air quality see ASHRAE Indoor Air Quality Guide (ASHRAE 2009).

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Chapter 7
Protective Design Practice

7.1 Main Concerns

Even though unlike the other chapters in this book in the contents of this section there is no reference or direct relationship to the general flow of other chapters which is energy conscious design and construction, but in a surprising relevant way, it would be reasonable to assume that a firm which has not worries about, and is not engaged in lawsuits or legal problems can produce higher quality designs and products. In other words, the personnel and economical resources that is utilized for fighting these unnecessary and unpleasant realities of professional world can be diverted and focused on better training of the employees, achieving basic and fundamental goals of any conscious architectural or engineering firm such as designing and constructing high-performance buildings and saving energy as a result. Also as I explained in earlier chapters of this book more energy efficient and sustainable building design can be achieved from utilization of performance based design due to its natural openness to innovations and new techniques that naturally make this type of design more vulnerable to possible lawsuits. Therefore understanding the basics of a protective design can indirectly but effectively help the advancement of the general goal of this book. This should be emphasized here that the material discussed in this chapter are solely based on my limited knowledge about the subject and by no means is based on neither my expertise in the subject nor my attempt to give legal advice. The only purpose is to make the readers familiar with the existence of such issues and encourage them to get legal advice from proper authorities when needed.

Since design and construction are integrated tasks that require many different professionals to act simultaneously without each of them having the real capability or even knowledge of controlling how good the other members are performing their designated responsibilities, it is critical for each firm and individual to protect their own firm and themselves from possibility of being exposed to the possible legal

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trouble, caused by his or anybody else's mistakes. This specifically requires that each individual to understand the design and construction governing circumstances, and each firm to sign only proper and well written contracts.

As a professional engages in performing his duties during design and construction of a building, there are plenty opportunities for committing different mistakes. Some mistakes are clear and obviously should not be committed, such as defaming others or damaging public health. But among all other possible but not clearly recognizable mistakes that a design or construction professional can make, probably those in the gray area are the ones proved to be mistakes caused by the designer's or contractor's negligence. Even though no one can deliver a flawless design or construction and neither anyone can expect a flawless design or construction, but the most important thing for a professional to keep in mind is that any possible firm or individual's mistake should not happen due to a negligence-based action. That is due to the fact that mistakes caused by negligence have the potential for possible severe legal liabilities, while pure honest mistakes may have not such potentials.

In addition to "negligence," "standard of care" is another very important definition that should be fully understood. Based on American Institute of Architects (AIA) standard of care is defined as: "The Architect shall perform its services consistent with the professional skill and care ordinarily provided by architects practicing in the same or similar locality under the same or similar circumstances. The architect shall perform its services as expeditiously as is consistent with such professional skill and care and the orderly progress of the Project." This definition is relevant for all other professionals such as engineers and contractors which are involved in building design and construction industry.

In the following sections of this chapter I discuss the basic factors and methods that an architect or engineer has to follow in order to engage in contracts cautiously, perform his duties based on the standard of care, and avoid actions that can be possible grounds for future legal confrontations based on the firm or individual's negligence.

7.2 Engaging in a Contract Agreement

The first step in starting an architectural or engineering design or construction project is the act of reaching an agreement between the professionals and the project owner. This requires both parties to engage in a contract agreement in order to clearly specify the needs and expectations of the owner and the responsibilities and the compensation of the professionals. Naturally every owner through the project contract language does his best effort to protect his money, get the best possible building and most lengthy and effective guarantees that he can get from the professionals. At the same time each professional does his best to design or build the best building in line with and even better than all governing codes and standards without exposing himself and his firm to unwanted conditions, moneywise or legal-wise, by agreeing to unrealistic and unachievable contracts.

As the first and perhaps the most obvious fact in a contract, a professional primary target is to provide his design or construction related services in exchange of money and therefore he should make sure that the proper provisions for adequate and timely payments have been anticipated in the contract document. At the same time make sure that enough clauses have been added to the contract that prevent possible penalties for him if unexpected project delivery delays happen.

In addition there are some contract clauses that in most situations are very valuable, and would be very helpful for the professionals to have it in their contracts, and in almost all cases could be to the benefit of the professionals to even abandon the contract, if the owner insists in removing them from the contract. Examples of these clauses are limitation of liability (to the standard of care) which basically limits the possible damages that one of contract signatories can ask from the other party (it is important to know that limitation of liability does not limit claims of other parties that have not signed the agreement), and ownership of instruments of service that means the architect and engineers will keep the ownership of their documents including design drawings and specification that they will produce for the owner. Therefore the design cannot be used for other projects in full or in part.

On the other hand there are a number of contract clauses that in most of the situations would be very harmful for the professionals to have it in their contracts, and in almost all cases could be so troublesome that it would be to the benefit of the professional to desert the contract if the owner insists in adding them to the contract. Examples of these clauses are committing to any type of certifications or guarantees.

The most comprehensive set of contract documents for architectural and engineering projects are provided by American Institute of Architects (AIA) and the Engineers Joint Contact Documents Committee (EJCDC). Usually these documents give the best fair protection to professional against unexpected clauses in the contract language. Therefore these are probably the best contract documents to be used, at least from the professional stances.

A new threat for the design and construction professionals has recently arisen from their commitment to design green buildings. Many times the owner is planning on receiving tax incentives, or even financial support from government, specific individuals or groups to build the building with a specific high level of sustainable building certification. If these levels are not achieved for any reason (design and construction professional deficiency or other reasons), then there will be financial unfavorable condition for the owner and he most probably will question the professional team members and even will try to transfer this burden towards them. The language of contract should only agree to employing reasonable effort for achieving these goals, without committing to any sort of guarantee or warranty for qualification to a specific level of sustainability scoring benchmark.

7.3 Negligence

In legal vocabulary torts are usually referred to as violation of the people from their personal or business duties. Also in these references torts are commonly divided to three major subsets of negligence, intentional violation and strict liability. As it was mentioned earlier, among all torts, negligence is the main one placed in a gray area that if can be proved can drag the professional into legal trouble. Negligence by definition is the proof of the professional failing to work with an acceptable level of concern. Basically three conditions shall be provided to make a case for proof of negligence. The first two conditions are the existence of an obligation or duty, and ground for believing the professional has failed to perform his work or deliver his obligation. The final condition of proof of negligence is the evidence that failing to perform this duty or obligation has caused measurable damage for another person or entity. Generally the existence of a contract, as well as architectural and engineering codes and standards can be used to produce the condition of existence of a responsibility for the architect or engineer to other persons or entities. Proof of violation from the contract most of the times requires an architectural or engineering expert witness, since the regular jury usually is not familiar with the laws, regulations, and common standards that the architects and engineers should bring their acceptable performance levels up to. Finally a reasonable connection should be existed between the lack of performance and claimed damages, and of course the damages should be quantifiable.

Intentional torts and strict liabilities which are the other two subcategories of torts are usually placed under a much clearer light from the legal stance and proper effort should be done to avoid them at all time. Intentional torts are those breaches of duty that are committed on purpose such as defamation of others, and strict liabilities are constructing buildings that could be dangerous for general public.

7.4 Standard of Care

Standard of care per AIA definition applies that the architect (and engineer) performance should not be expected to be perfect, but it should be in line with the degree of skills ordinarily for any reputable professional in the same field and in the similar regions. This is a very reasonable and fair standard, and any architect or engineer should strongly resist replacing of this performance requirement level with any higher level of care in the language of his contract.

Not only the legal system understands that the professionals should not be hold responsible to perform a perfect and flawless service, but also the insurance companies that provide coverage for the architectural and engineering firms provide insurance for the companies only up to the level of standard of care. Therefore including any language that may possibly create a more stringent level of obligation expectancy in the contract should be avoided. Including such languages in contract if nothing else will provide a possible ground for the firm loss of insurance. In other words it is likely that insurance companies will not provide coverage for the architect or engineer companies above the standard of care, even if they promise performance beyond and above that.

7.5 Summary

The most comprehensive set of contract documents for architectural and engineering projects are provided by American Institute of Architects (AIA) and the Engineers Joint Contact Documents Committee (EJCDC). It is to the benefit of the professionals generally to use these documents as the basis of an agreement between them and the owners. These documents have been written carefully to define the responsibilities of both professionals and owners. These documents have been vigilantly reviewed and adjusted by architects, engineers, contractors, and insurance companies during the time, to minimize the possibility of unexpected interpretations from the clauses in the agreements. Of course some owners hesitate to sign contracts unless they are using their own version of contract documents. In this case the professional should be very cautious about what he is agreeing to, and it is very important to let the company attorney and insurer review the contract and revise it before they commit to the contract.

When a professional commits to do a project and therefore engages in a contract based on a client generated document (or as a matter of fact based on any type of contract), there are a few issues that should be carefully looked into and cautiously worded in the contract agreement to help protecting the professionals and their firms against the possible future troubles.

As it was discussed earlier any provisions that imply any kind of guarantee or certification including certification of compliance to codes should be carefully eliminated from the contract wording.

Another very important thing to consider is to make sure there is a clear explanation of the scope of the deliverables. Professionals should make it completely clear what is the final product that they are going to provide to the owner and what is not part of the agreement to be delivered as this final product. It is always to the benefit of all the involved parties and also the project itself to make it clear what are the expectations from each party which is involved in the project in advance.

And finally, the professional shall do his best to provide maximum effort to deliver the project at least in-line with the common standard of care without allowing any type of negligence. it is as important for the professionals not to allow any language implying a performance level above the common standard of care to be added to the contract documents, and do not accept any wording implying higher threshold for fault acceptance than what is explained in AIA or EJCDC documents.

Part IV
Systems and Controls

Chapter 8
HVAC Systems

8.1 Early Years

Wind tower structures were used to provide natural air conditioning and humidification in hot and dry climates in central parts of ancient Iran. As wind entered to the structure from the top of the tower and through the flaps it was directed down inside of the building and therefore created a sense of air movement for the people inside the building. A cistern in the bottom of the tower used to create some sort of humidity control inside the tower as the air passed over it.

Samuel Sugarman in his book "HVAC Fundamentals" (Sugarman 2007) has a comprehensive look at HVAC systems history and operations. Regarding the history of HVAC systems, he depicted a timeline starting year 1000 and has divided it into four major recognizable eras. In first 500 years of this timeline, some of the main HVAC related inventions were invention of fans that were operating either by man power or water power in Egypt and Italy. In the following 200 years some of the major HVAC-related inventions were included utilization of ventilating machines for ventilating the mines which was invented in France, invention of thermometer by Galileo and development of a thermometer independent from the air pressure by Ferdinand II. Between years 1700 and 1900 Fahrenheit invented mercury thermometer, Benjamin Franklin invented first steam heating system followed by James Watt's steam engine; Carnot founded thermodynamics and James Joule discovered that work produces heat, and heat started to be considered as energy. In this era law of conservation of energy was discovered, along with first and second laws of thermodynamics. Finally after year 1900, HVAC systems improved dramatically and systems such as furnace with centrifugal fans, and high pressure steam heating systems were widely utilized. First centrifugal refrigeration machine was made for air conditioning of the large spaces. Pumps and radiators started to be utilized and first refrigeration system with a compressor was invented which led to residential air

J. Khazaii, *Energy-Efficient HVAC Design*, DOI 10.1007/978-3-319-11047-9_8

conditioning systems. Invention of the heat pumps was an advancement that created the ability of the space cooling when cooling is required and ability of space heating when heating is required with the same unit while utilizing reverse cycles (Khazaii 2012).

8.2 New Era and Attention Towards Energy Efficiency

The definition of efficiency for different equipment is generally referred to the ratio of the effective or useful output to the required total input of the equipment. The Air Conditioning and Refrigeration Institute (ARI (also known as AHRI)) is an institute that regulates how the manufacturers have to perform performance tests and how to publish the efficiency of their products based on the outcome of those tests. Of course the published values shall describe the efficiency of the equipment under full and part load conditions. As it was noted earlier, the efficiency of different equipment shall be defined by the ratio of effective to implied energy. For example the efficiency of a fan should be stated as ratio of power transferred to the airflow and the power used by the fan.

Different reference resources have categorized HVAC systems in different ways, but two most universally accepted methods to categorize these systems that are also in-line with ASHRAE systems handbook (ASHRAE 2012) definition are dividing them into either centralized and decentralized systems, or all air, air-water, and all water systems.

To ensure receiving high performances from the HVAC systems, different reference books have offered different prescriptive guidance, e.g. higher workmanship for construction materials, advance control strategies and of course higher equipment efficiency. Some of these sources have also suggested performing simulations (energy modeling) in order to ensure achieving a minimum acceptable performance for the whole building including its HVAC system.

One of the methods that is regularly used in practice for energy efficiency evaluation is structured in ANSI/IESNA/ASHRAE Standard 90.1-2013 (ASHRAE 2013) which in order to specify the energy efficiency of the building demands performing either a prescriptive based analysis or running a simulation based modeling for the targeted building. The simulation-based method further requires comparing the simulation results with the results of another simulation for an imaginary equivalent building that its structure is described and known as the baseline building in ASHRAE standard 90.1 (ASHRAE 2013). The amount of saved energy (cost) in design building compared to the imaginary building will be represented as the degree of energy efficiency of the design building (Khazaii 2012).

Simulation software basically provides yearly energy consumption output for the specific building in a specific climate under full and part load condition of the HVAC system based on various building and system inputs. But there are some other major considerations that can affect the overall efficiency of a system as well. These considerations cannot be translated into quantitative measures easily and almost all of the simulation software packages lack the capacity to include these parameters in their final analysis. Considerations such as acoustical impact, space saving and degree of affecting other trades are examples of these parameters. To include such parameters in overall system efficiency the most usual method is relying on expert interview results as well as literature research, and not as part of the general body of the simulation (Khazaii 2012).

In order to reduce the consumed energy of each system, an important step is to understand which equipment and other elements are used to construct the targeted system and of course which parts of each equipment or element are the main energy consumers. After completing this vital step we can concentrate on selecting and improving the efficiency of these equipment and elements in order to improve the overall system efficiency. Here I will provide a brief informational review of some of the most used current HVAC systems and specify its energy consuming parts.

8.3 A Brief Review of the Most Applicable HVAC Systems

In this section I will investigate some of the most applicable HVAC systems as they are commonly being utilized for conditioning of commercial buildings such as office buildings, institutional and healthcare facilities. The main target of this section in addition to provide a general understanding about the different available types of modern HVAC systems is to shed light on the major energy consuming parts of each system that improving them can be translated to improvement of the overall efficiency of the system. For more detail see (Khazaii 2012).

8.4 Chilled Water Systems (Chillers)

Chillers are the center piece of the chilled water systems which its function is to generate proper chilled water quantity with proper temperature, in order to facilitate cooling of the delivered air entering the targeted spaces and to remove the heat from the inside of the building. This function is done by utilizing the cooling coil at main air handling unit serving the targeted spaces. This removed heat from the spaces, increases the chilled water temperature. Warmer chilled water heat then will be transferred to the outdoor via a water-cooled (including cooling towers and pumps) (Fig. 8.1), or air-cooled mechanism. Chilled water systems are usually being utilized in the larger systems because they have the advantage of better controllability than the other alternatives such as direct expansion unitary (DX) systems. Chillers are usually built and tested as package units in the factory, before delivery and installation on the site. This reduces the risk associated with lower quality field labor and testing procedure considerably.

In the heart of most of the chillers there is a refrigerant cycle which operates via circulating an operating refrigerant, which is circulated and changes states to facilitate

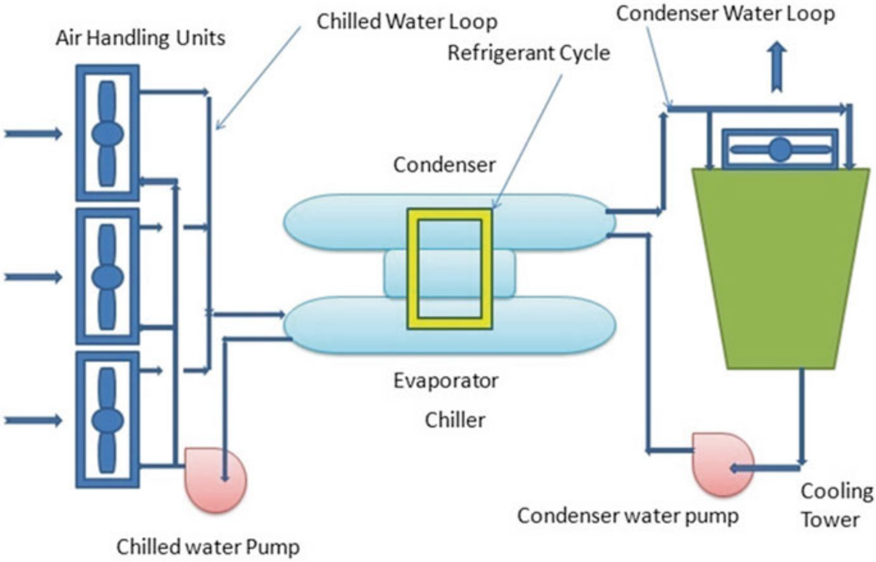

Fig. 8.1 Chilled water system

the desired functions in evaporators and condensers. Using a central chiller plant instead of having multiple cooling devices throughout the building helps to limit the existence of the refrigerant in a central location. This means monitoring, controlling and evacuating expense of the stored refrigerant in a chiller assembly in case of occurrence of refrigerant leak accident in the site can be limited to a central location instead of multiple locations.

The main sources of energy consumption in air- or water-cooled chilled water systems are power required for running the chiller (compressor), power required for running the fan at cooling tower (Condenser fans in air cooled system), and power required to run the pumps. Heat transfer to and from the pipes can indirectly increase the energy consumption of the system also. The small energy consumed by low voltage power provided for control valves is another source of energy consumption. There is always electrical power consumption for heat tracing the water piping outside the heated mechanical rooms, and protecting the cooling tower basins from freezing. It should be noted here that energy consumers of the airside of the system will be discussed later in this chapter.

8.5 Heating Systems (Boilers)

A boiler by definition is a closed heating appliance that its function is to provide either hot water or steam for power generation, processing, and space heating. It is common to subcategorize the boilers to low pressure and high pressure. For a hot

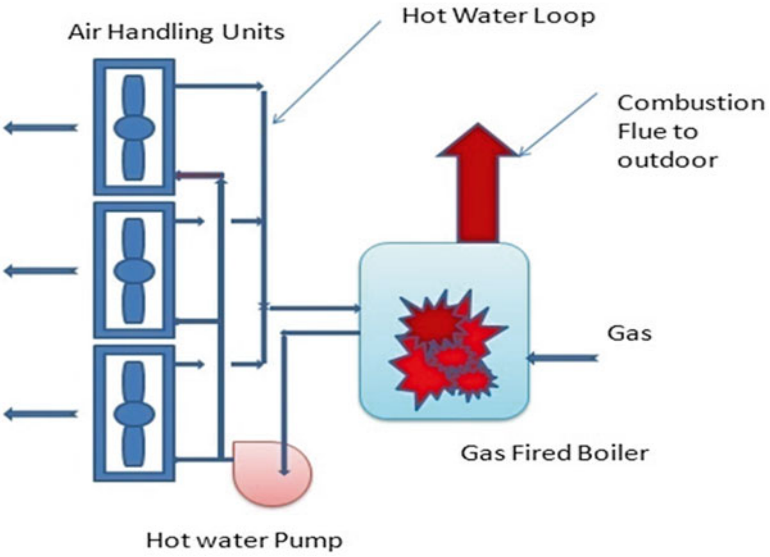

Fig. 8.2 Hot water boiler system

water boiler (Fig. 8.2), the separating pressure limit between low and high pressure is one hundred and sixty pounds per square inch (160 psi), while the separation limit for steam boilers is fifteen pounds per square inch (15 psi). The maximum temperature limit for a low pressure hot water boiler is at two hundred and fifty degree Fahrenheit (250 °F).

Other methods of categorization of different boilers can be based on its condensing and non-condensing capability, construction material type, type of draft (natural or forced), or water tube versus fire tube types.

Based on type of construction material category most of the non-condensing boilers are made of either cast iron sections, steel or from copper. The first type is known as cast iron sectional and the second type is referred to as cooper finned tube boilers. Condensing boilers are usually made of stainless steel or aluminum to protect the body of the boiler from condensation corrosion. Typical efficiency of good cast iron sectional boilers is around 80–84 %, while a good copper finned tube boiler can produce efficiencies close to 90 %, or even higher.

The advantage of the condensing boilers over the other types of boilers made for the space heating purpose is in their very high efficiencies and energy saving characteristics. Roughly about 10 % of the energy (BTU) content in each cubic foot of natural gas burned in a gas fired boiler leaves the stack in the form of latent heat of vaporization for water. Allowing this vapor to condense and to bring down the stack temperature implies very high boiler efficiency. A good condensing boiler can deliver an efficiency of up to 98 %, when the inlet water temperature sets as low as 110 °F.

Based on the international mechanical code (ICC 2012) definition modular boilers are a group of individual boilers installed as a unit without any stop valve in between. The individual modules input should not exceed four hundred thousand British thermal units per hour (400,000 Btu/h) gas or one hundred and fourteen kilowatts (114 kW) electric.

Fire tube versus water tube boilers are another well known categorization for the boilers, which refers to the locations of water and fire inside and outside of the boiler tubes.

A force draft boiler utilizes a fan to generate required force for discharging the combustion products into atmosphere, while a natural draft boiler relies on the buoyancy of natural pressure differences to move the combustion product up the flue stack.

A hot water boiler system (Fig. 8.2) that is used for space heating purpose is commonly consisted of a number of boilers that generate hot water, a group of pumps that distributes the hot water through a network of hot water piping to air handling units preheat and heating coils, or other heating equipment such as hot water unit heaters. The common source of heating generation in gas-fired boilers is natural gas, and in electric boilers is electricity.

Therefore other than power required for pumping the hot water in a hot water heating system, the electrical power required for this system are power required for forced draft combustion discharge fan, electric power for burner ignition, and in case of using an electric boiler is the boiler own power (KW). Heat transfer from pipes can indirectly increase the energy consumption of the system also. The small energy consumed by low-voltage power provided for control valves is another source of energy consumption.

8.6 Direct Expansion (DX) Unitary Systems

In a direct-expansion unitary system, the evaporator of the refrigerant cycle is in direct contact with the air stream. These units can be found in the forms of packaged or split system units. If the evaporator and condenser are located in the same enclosure, the unit is called packaged and if the evaporator and condenser are located separately inside and outside of the building these units are known as split systems. The main reason for using this type system is its lower cost due to its lower required labor and also fewer components to install. The other factors that affect the decision in selecting direct expansion versus other systems are less required space, its availability in a variety of small capacities, and simpler controls.

The main sources of energy consumption in direct expansion systems are power required for running the direct expansion system compressor and condenser fan, power required for running the airside supply fan, and power required for running terminal unit fans (if any) (this will be discussed in more detail when I discuss the airside systems later in this chapter). The small energy consumed by low voltage power provided for control valves is another source of energy consumption.

8.7 Variable Volume Package Rooftop Unit

This system (Fig. 8.3) is constructed of one or two airside fans (supply and return/exhaust), direct expansion cooling coil that absorbs the heat from the inside and rejects that heat to the outside via condenser, and its fan assembly. This eliminates the associate cost with separate chiller, chilled water pumps, cooling tower, and condenser water pumps. Supply fan delivers a variable air volume to the terminal units and return/exhaust fan modulate in track with the supply air to provide a proper air balance in the building.

The main energy consumers in the system are supply fan power input, return fan (if it is provided) power input, compressor power input, condenser fans power input, and terminal units fan power input. Heat transfer through the ducts and duct air leakage also contribute to energy consumption (waste) in this system. The small energy consumed by low voltage power provided for control valves is another source of energy consumption.

8.8 Self-Contained Water-Cooled Air Conditioner

This system (Fig. 8.4) is constructed of one or two airside fans (supply and return/exhaust), and direct expansion cooling coil that absorbs the heat from the inside and rejects that heat to the condenser water loop. This heat then will be rejected to the

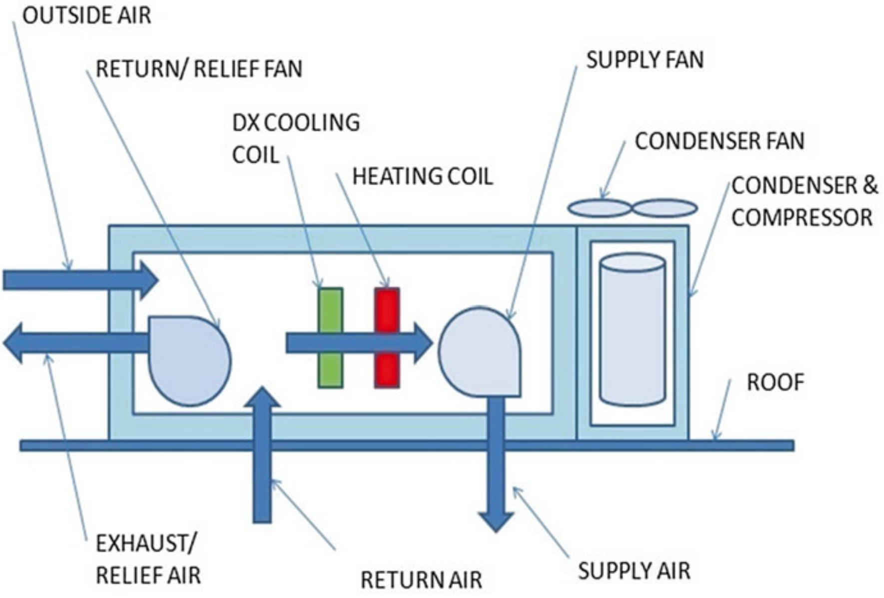

Fig. 8.3 Variable volume package rooftop unit

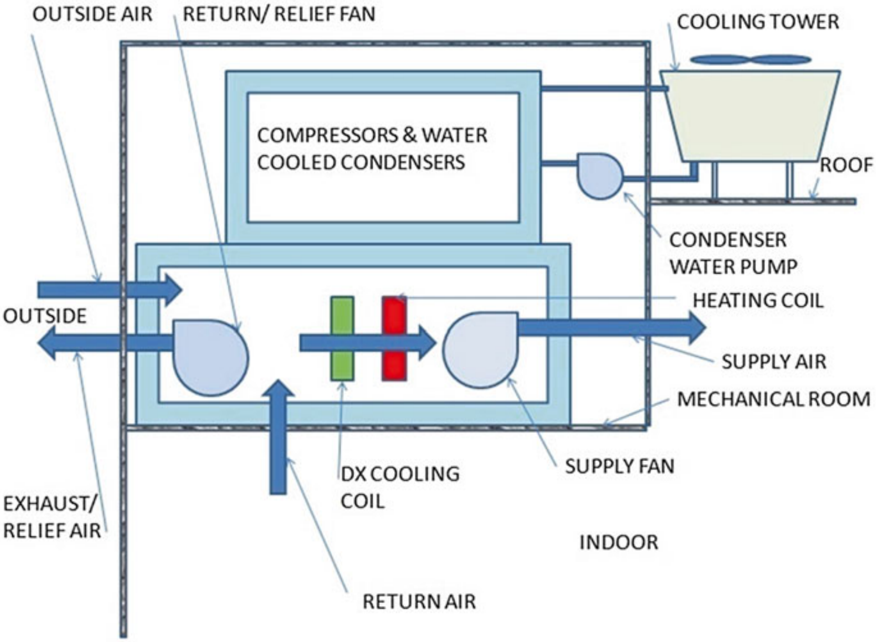

Fig. 8.4 Self-contained water-cooled system

atmosphere through cooling tower. Cooling tower receives this water through the condenser water pipes and pumps. There is no need for a separate chiller, and neither there is a need for chilled water pumps in this arrangement. Supply fan delivers a variable air volume to the terminal units and return/exhaust fan modulate simultaneously with the supply air to provide the desired air balance in the building.

The main energy consumers in the system are supply fan power input, return fan (if it is provided) power input, compressor power input, cooling tower fan, condenser water pumps and terminal units fan power input. Heat transfer through the ducts and duct air leakage also contribute to energy consumption (waste) in this system. There is always electrical power consumption for heat tracing the water piping outside the heated mechanical rooms, and protecting the cooling tower basins from freezing.

The small energy consumed by low-voltage power provided for control valves is another source of energy consumption.

8.9 Packaged Terminal Air Conditioner

A separate Packaged Terminal Air Conditioner (PTAC) including a fan, filter, direct expansion cooling coil, and hot water/electric heating coil/strip if it is needed is located in each room. The unit supplies a constant volume of conditioned air to the room and meeting the varying load is controlled via cooling and heating control valves modulation, or through the steps of the electric heating coil.

The sources of energy consumption in this system are supply fan motor input power, electric heating strip (if it is used) power requirement, and compressor and condenser power input. The small energy consumed by low-voltage power provided for control valves is another source of energy consumption.

8.10 Water Source Heat Pump

In this system an individual constant volume cooling and heating heat pump is designated to each space, and as the space load varies, unit refrigerant cycle operates to satisfy the load requirement of the space. Any time the space temperature moves above the cooling temperature set point, the cooling refrigerant coil will be energized and fan delivers a constant temperature cooling supply air to cool the room. Condenser water then absorbs the heat from the refrigeration cycle, and rejects it to outdoor. In some condition this absorbed heat even may be used to heat the other parts of the building, which are in need for heating. Heat pumps heat rejection water loops usually are equipped with heat rejection equipment such as cooling tower(s), and heat adding equipment such as boiler(s) and of course circulating pumps. The sources of energy consumption in this type of systems are supply fan motor input power, electric preheat and reheat coils, compressor power input, pumps power input and cooling tower fans required power. Duct air leakage, heat transfer from ducts and pipes, and efficiency loss in water coils are other sources that can indirectly increase the energy consumption of the system. Also power required to run the boiler if necessary could be another source of energy consumption.

The small energy consumed by low-voltage power provided for control valves and dampers is the other source of energy consumption. There is always electrical power consumption for heat tracing the water piping outside the heated mechanical rooms, and protecting the cooling tower basins from freezing (Khazaii 2012).

8.11 Ground Source Heat Pumps

A typical ground source heat pump is similar to a traditional water source heat pump system equipped with cooling tower and boiler except that with a ground source heat pump system there is the opportunity for reducing or eliminating the need for using cooling tower and boiler. This fact helps the building to consume less energy by replacing the cooling and heating processes derived from cooling tower and boiler system, by taking advantage from the fact that the ground stays in an almost constant temperature as a heat sink and heat source throughout the year.

Ground source heat pumps can be categorized into three major types: (1) ground-coupled closed heat pump system which uses special high density polyethylene pipes located in the ground, (2) surface water closed heat pump system which uses similar pipes located under the water in a lake or pond, and (3) ground water open heat pump system which uses the pumped water from a well and an additional heat exchanger to deliver water to a close loop system inside the building.

Each of these systems has its advantages and disadvantages. Due to the closed loop configuration of the ground coupled heat pump system, this system does not need a constant supply of a large quantity of water and also does not require any type of water treatment. The main disadvantage of this system is the high cost of drilling down the earth for installation of the pipes.

Surface water closed heat pump system uses the water in the pond or lake that has a high thermal conductivity and therefore is very useful for heat transfer to and from the lake or pond water to the water in the building loop. Same as previous type there is no need for water treatment due to closed building loop. It is also less expensive due to lack or need for deep drilling necessary for the previous system. The disadvantage of this system is its need for an available large lake or pond to submerge the heat exchanging pipes.

Finally ground water open heat pump system is less expensive due to lower cost of drilling a well compared to that of required for ground-coupled systems, but requires continuous supply of well water and also water treatment provisions.

In some specific climate condition and due to lack of access to very large sources of ground space or available water capacity a small cooling tower or boiler should be added to the system to supplement the functions of the ground, or water as the soul sources of heat exchange in a hybrid configuration.

The sources of energy consumption in this type of systems are supply fan motor input power, electric preheat and reheat coils, compressor power input, pumps power input, and cooling tower fans (if it is required) required power. Duct air leakage, heat transfer from ducts and pipes, and efficiency loss in water coils are other sources that can indirectly increase the energy consumption of the system. Also power required to run the boiler if it is necessary could be another source of energy consumption.

The small energy consumed by low voltage power provided for control valves and dampers is the other source of energy consumption. There is always electrical power consumption for heat tracing the water piping outside the heated mechanical rooms, and protecting the cooling tower basins from freezing.

8.12 Airside Systems

8.12.1 Traditional Airside HVAC Systems

It should be noted here that in the remaining part of this section, when I talk about the power required for running the system, the focus is mainly on the power required for the airside operation only. Of course all the power consumers that were discussed under the chiller, cooling systems, boiler and heating systems sections would be part of the overall system power consumers of the following airside systems where they are applicable.

8.12.2 Constant Air Volume System with Bypass Variable Air Volume Terminal Units with Reheat

This system (Fig. 8.5) is consisted of a central constant volume supply fan that supplies conditioned air to all the local variable air volume terminal boxes through a network of ducts. Quantity and temperature of the mixture of the air which is delivered to each room is designed based on the room sensible load, the quantity and temperature of the outdoor air in the mixture, and space thermostat setting. Additional part of the air that is not needed for conditioning each space is bypassed into a common return air path and after getting mixed with the return air from all the other spaces goes back to the air handling unit as return air stream usually with the help of a return/exhaust fan. Terminal units are also equipped with hot water reheat coils or electrical strips that are designed for either heating or dehumidification of the discharged air to each space.

The sources of energy consumption in this type of systems are air handling unit supply fan motor input power, return/exhaust fan motor input power, hot water

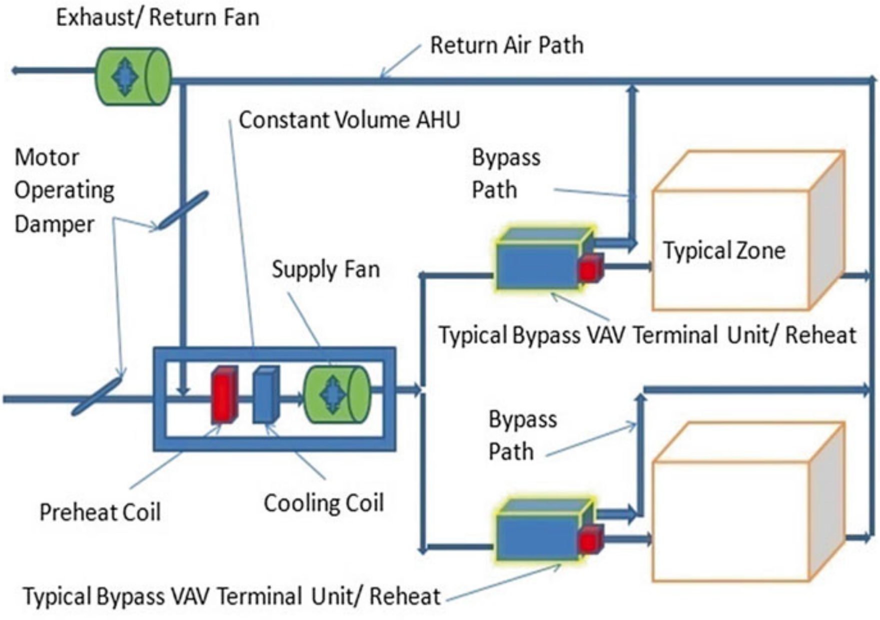

Fig. 8.5 Constant air volume system with bypass variable air volume terminal units with reheat

pumps or electric preheat strip (if it is used for freeze protection instead of hot water coil) in air handling unit, and hot water pumps or electric reheat strip (if it is used for dehumidification or heating instead of hot water coil). Duct air leakage, heat transfer from ducts, and efficiency loss in water coils are other sources that can indirectly increase the energy consumption of the system. The small energy consumed by the low-voltage power provided for control valves and dampers is the other source of energy consumption.

8.12.3 Variable Air Volume System with Variable Volume Terminal Units with Reheat

This system (Fig. 8.6) is made of a central variable volume supply fan that supplies conditioned air to all the room's variable air volume terminal units through a medium pressure duct network. Quantity and temperature of the mixture of the air which is delivered to each room is designed based on the room sensible load, the quantity and temperature of the outdoor air in the mixture, and space thermostat setting. The exiting air from all the spaces goes back to the air handling unit as return air stream usually with the help of a return/exhaust fan. A variable frequency drive modulates the supply fan to provide air flow equal to the sum of all the terminal units' airflow in every instant. (Terminal units are also equipped with

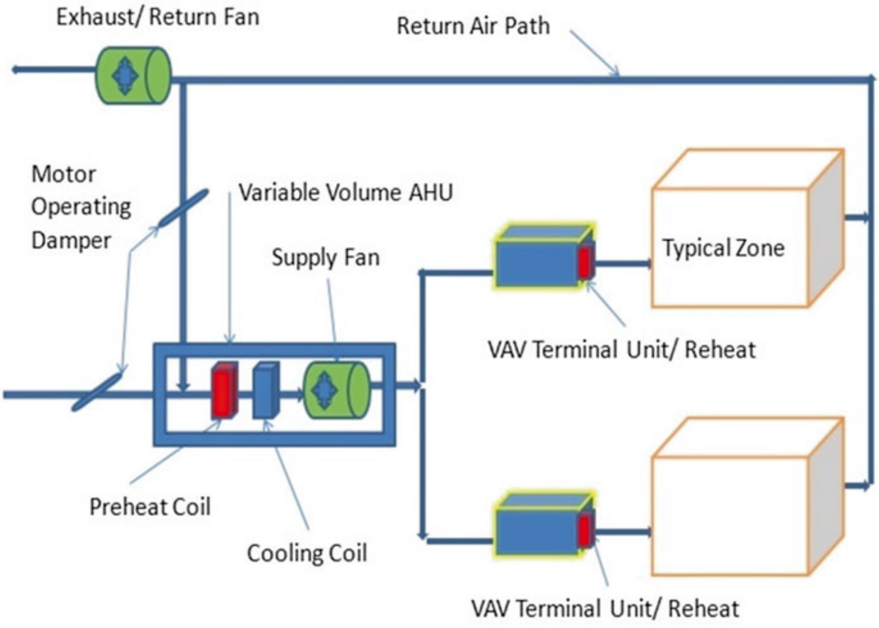

Fig. 8.6 Variable air volume system with variable volume terminal units with reheat

hot water reheat coils or electrical strips that are designed for either heating or dehumidification of the air).

The sources of energy consumption in this type of systems are air handling unit supply fan motor input power, return/exhaust fan motor input power, hot water pumps or electric preheat coil (if it is used for freeze protection instead of hot water coil) in air handling unit and hot water pumps or electric reheat (if it is used for dehumidification or heating instead of hot water coil). Duct air leakage, heat transfer from ducts, and efficiency loss in water coils are other sources that can indirectly increase the energy consumption of the system. The small energy consumed by the low-voltage power provided for control valves and dampers is the other source of energy consumption.

8.12.4 Variable Air Volume System with Parallel Fan Powered Units

This system (Fig. 8.7) is consisted of a central, variable volume supply fan that supplies conditioned air to all the local parallel fan-powered variable air volume terminal units through a network of medium pressure supply ducts. Quantity and temperature of the mixture of the air which is delivered to each room is designed based on the room sensible load, the quantity and temperature of the outdoor air in

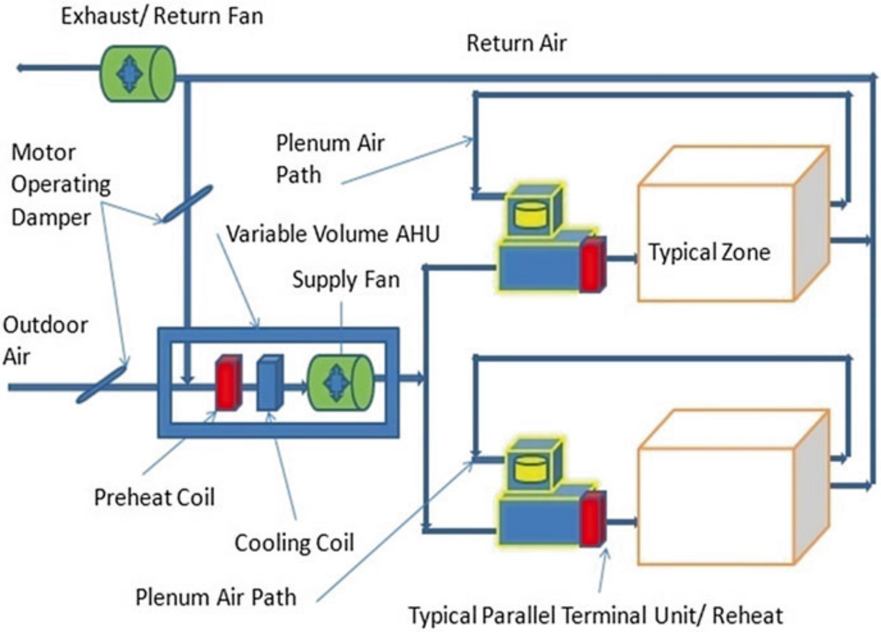

Fig. 8.7 Variable air volume system with parallel fan powered units

the mixture, and space thermostat setting. In this system a variable frequency drive (VFD) is used to modulate the air handling unit supply fan. Supply fan then provides a total air flow equal to the airflow quantity required (in each instant) to the sum of all the terminal unit's primary airflows. This primary air then will be mixed with some of the plenum air through the terminal unit constant volume fan as needed before being discharged to the room (Terminal units are also equipped with hot water reheat coils or electrical strips that are designed for either heating or dehumidification of the air).

The sources of energy consumption in this type of systems are air handling unit supply fan motor input power, return fan motor input power, hot water pumps or electric preheat strips (if it is used for freeze protection instead of hot water coil) in air handling unit and hot water pumps or electric reheat strip (if it is used for dehumidification or heating instead of hot water coil). Duct air leakage, heat transfer from ducts, and efficiency loss in water coils are other sources that can indirectly increase the energy consumption of the system. The small energy consumed by the low-voltage power provided for control valves and dampers is the other source of energy consumption (Khazaii 2012).

8.12.5 Variable Air Volume System with Series Fan-Powered Units

This system (Fig. 8.8) is made of a central variable volume supply fan that supplies conditioned air to all the room's series fan-powered VAV terminal units through medium pressure ducts. Each room will receive a constant quantity of air. Quantity and temperature of the mixture of the air which is delivered to each room is designed based on the room sensible load, the quantity and temperature of the outdoor air in the mixture, and space thermostat setting. In this system a variable frequency drive (VFD) is used to modulate the air handling unit supply fan. Supply fan then provides a total air flow equal to the airflow quantity required (in each instant) to the sum of all the active terminal unit's primary airflows. This primary air then will be mixed with some of the plenum air and a constant flow will be delivered to the space, any time room requires conditioning. (Terminal units are also equipped with hot water reheat coils or electrical strips that are designed for either heating or dehumidification of the air). This type unit is usually used for special spaces such as conference rooms that require large quantity of air at all time due to the space relatively large occupancy.

The sources of energy consumption in this type of systems are air handling unit supply fan motor input power, return/exhaust fan motor input power, terminal unit fan motor input power, hot water pumps or electric preheat strips (if it is used for freeze protection instead of hot water coil) in air handling unit, and hot water pumps or electric reheat strips (if it is used for dehumidification or heating instead of hot water coil). Duct air leakage, heat transfer from ducts, and efficiency loss in water coils are other sources that can indirectly increase the energy consumption of the system.

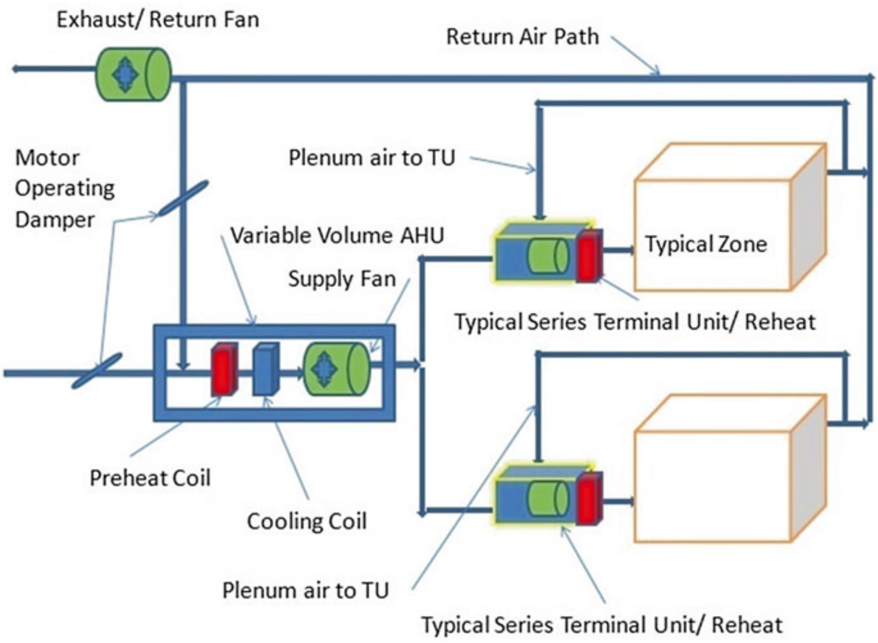

Fig. 8.8 Variable air volume system with series fan-powered units

The small energy consumed by low-voltage power provided for control valves and dampers, and the power input to the variable frequency drives for supply and return fans that can be factored in supply and return fan consumption itself are the other sources of energy consumption (Khazaii 2012).

8.12.6 Changeover Bypass VVT

The difference between this system (Fig. 8.9) and bypass variable air volume system is that in the later system each terminal unit bypasses the air individually, but in this system bypassing is done through designated bypass variable air volume boxes. The main air handling unit remains constant volume.

The sources of energy consumption in this type of systems are air handling unit supply fan motor input power, return/exhaust fan motor input power, electric preheat strip (if it is used for freeze protection instead of hot water coil) in air handling unit, and electric reheat strip (if it is used for dehumidification or heating instead of hot water coil).

Duct air leakage, heat transfer from ducts, and efficiency loss in water coils are other sources that can indirectly increase the energy consumption of the system. The small energy consumed by low voltage power provided for control valves and dampers is the other source of energy consumption (Khazaii 2012).

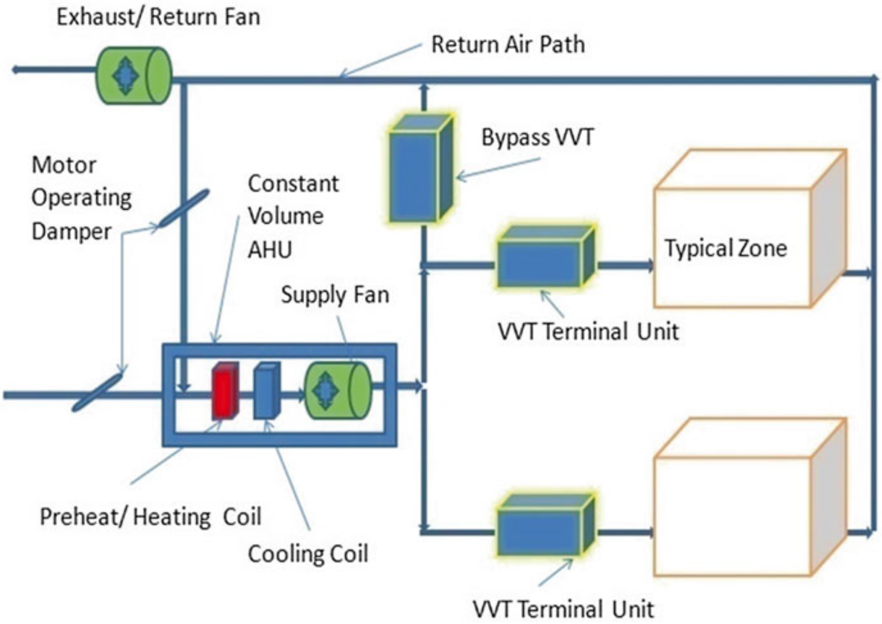

Fig. 8.9 Changeover bypass VVT

8.12.7 Fan Coil Units

In this system (Fig. 8.10) a separate fan coil unit or unit ventilator (including a fan, filter, cooling coil, and heating coil if it is needed) is located in each zone. Central heating and cooling plants provide required heating and cooling for the respected coil (chilled water, hot water, or steam). Basically the unit supplies a constant quantity of conditioned air to the zone and the coils control valves modulate to meet the varying load. In large systems, dedicated outdoor air units will deliver preheated or precooled outside air through a network of ductworks to the mixing air plenum installed in the back of the fan coil units, which mixes this outside air with the return air from the room before moving the mixed air through the fan coil fan.

The sources of energy consumption in this type of systems are fan coil unit supply fan motor input power and electric heat strip (if it is used instead of hot water coil) in fan coil unit. Duct air leakage, heat transfer from ducts, and efficiency loss in water coils are other sources that can indirectly increase the energy consumption of the system. The small energy consumption made by low voltage power input for the control valves and dampers is the other source of energy consumption (Khazaii 2012).

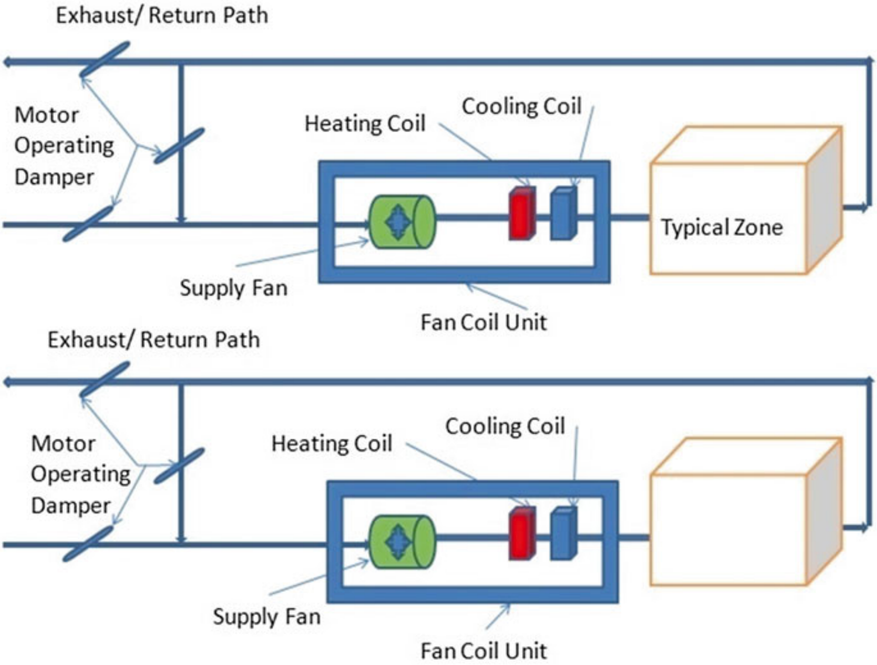

Fig. 8.10 Fan coil unit

8.13 Advance Energy-Efficient Airside HVAC Systems

8.13.1 Under-Floor Air Distribution CV

Under-floor air distribution systems (Fig. 8.11) were invented and used in the 1950s for cooling spaces with higher than usual heat loads such as computer rooms. The basic concepts are (1) to replace the ductwork network with an open space between the structure slab and raised floor, and (2) to deliver the conditioned air immediately to lower part of the room where people actually stay and work.

This system is similar to a variable-temperature, constant-volume system, except that (1) instead of using the duct for air delivery, it uses the under-floor plenum space, (2) there is an additional return-air bypass arrangement which is used to bypass return air to upstream of the fan in order to provide sufficient dehumidification when it is needed, without the need for a reheat coil, and (3) an additional baseboard radiators or convectors is used for space heating.

This system not only results in saving energy by delivering air with a higher temperature than what is usually used in traditional cooling systems (in this system

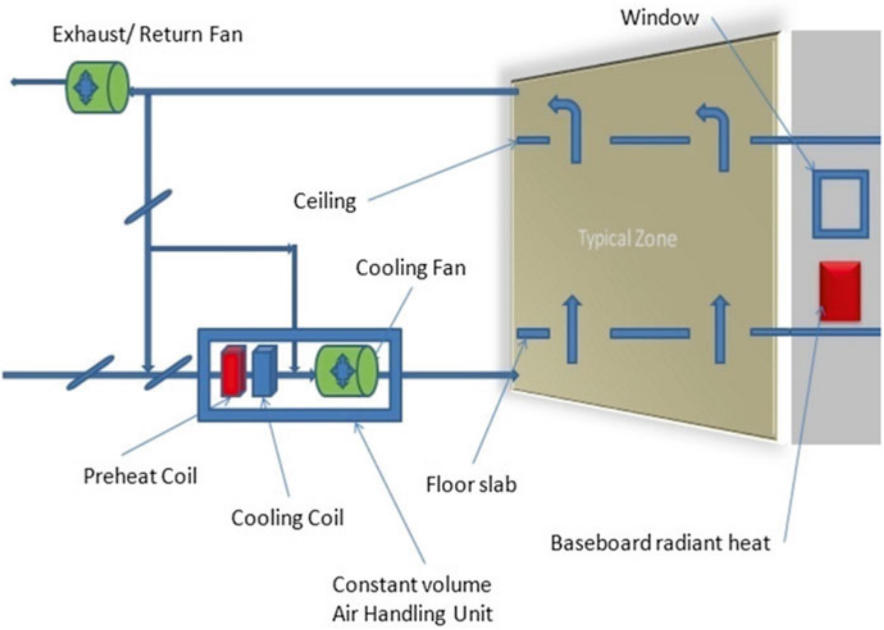

Fig. 8.11 Under-floor air distribution CV

discharge air is usually cooled down to only around 63 °F instead of 55 °F which is normally done in traditional systems), but also creates higher occupant comfort by delivering air with lower speed than what is used in traditional systems, and where it is most effective. ASHRAE standard 55 (ASHRAE 2010) recommends a maximum vertical air temperature difference of 5 °F between heights of 67 and 4 in. from the floor which is usually where the occupants head and foot are located. Cooling air stratifies towards the ceiling where the air finds a return path to the air handling unit and creates a comfortable occupied zone in the lowest six feet of the room where actually occupants live and then leaves the room with a higher temperature through the upper unoccupied section of the room and finally from available path on the ceiling. In regards to the advantages of any configuration of the under-floor systems over the traditional systems, it easily can be seen that the under-floor air distribution systems are more energy efficient due to its required higher cold air temperature for air conditioning. In addition even more energy saving opportunity is created any time the room sensible load decreases. In this condition the supply air temperature can be increased to even higher than 63 °F and results in an even larger decrease in cooling consumption. Also, there is a much larger chance and available opportunity for utilizing the economizer cycle for this system due to the higher possibility of outdoor air temperature meeting the economizer cycle acceptable requirements. Another energy saving opportunity appears as the result of lower consumed energy by the air handling unit fan, due to lower pressure loss in the system compare to the traditional systems with extensive duct network. In addition it is likely that people feel more comfortable with using this system because of a simpler access to the diffusers on the floor instead of over-head diffusers, and a better air quality due to its immediate arrival of air to people breathing zone. On the other hand the main disadvantages and concerns about this system are lack of enough designer experience with this new system, difficulty of using these systems in existing buildings and higher cost for raised floor construction.

Bauman in his book (Bauman 2003) provides an in depth evaluation and provides design guidelines for designing under-floor air distribution systems.

The sources of energy consumption in this type of systems are the air handling unit supply fan motor input power, return fan motor input power, electric preheat strip (if it is used for freeze protection instead of hot water coil) in air handling unit and baseboard electric units (if it is used). Ductwork (between the air handling unit and the under-floor plenum) air leakage, heat transfer from ducts, and efficiency loss in water coils are other sources that can indirectly increase the energy consumption of the system. The small energy consumed by low-voltage power provided for control valves and dampers is the other source of energy consumption.

8.13.2 Under-Floor Air Distribution Parallel Fan-Powered VAV

This system (Fig. 8.12) is similar to a parallel fan-powered variable air volume system except that (1) instead of using the duct for air delivery, it uses the under-floor plenum space, (2) there is an additional return-air bypass arrangement which is used to bypass return air to upstream of the fan in order to provide sufficient dehumidification when it is needed, without the need for a reheat coil, and (3) space heating is delivered through an under-floor parallel variable air volume terminal unit that draws air from the room rather than the ceiling plenum.

Utilizing this system similar to the previous system not only results in saving energy by delivering air with a higher temperature than what is usually used in traditional cooling systems, but also creates higher occupant comfort by delivering air with lower speed than what is used in traditional systems, and where it is most effective. The sources of energy consumption in this type of systems are the air handling unit supply fan motor input power, return fan motor input power, terminal unit fan motor input power, electric preheat strip (if it is used for freeze protection instead of hot water coil) in air handling unit and electric reheat strip (if it is used for dehumidification or heating instead of hot water coil) in terminal unit.

Duct air leakage, heat transfer from ducts connecting air handling unit to the under floor plenum, and efficiency loss in water coils are other sources that can indirectly increase the energy consumption of the system. The small energy consumed by low voltage power provided for control valves and dampers, and the power input to the variable frequency drives for supply and return fans that can be factored in supply and return fan consumption itself are the other sources of energy consumption.

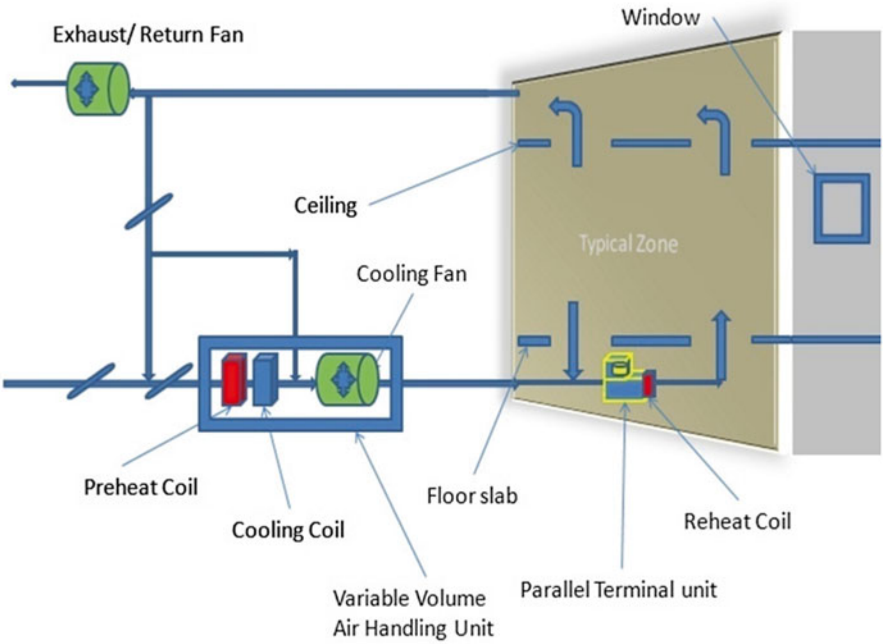

Fig. 8.12 Under-floor air distribution parallel fan-powered VAV

8.13.3 Under-Floor Air Distribution Series Fan-Powered VAV

This system (Fig. 8.13) is similar to a series fan-powered variable air volume system, except that (1) instead of using the duct for air delivery, it uses the under-floor plenum space, (2) there is an additional return-air bypass arrangement which is used to by-pass return air to upstream of the fan in order to provide sufficient dehumidification when it is needed, without the need for a reheat coil, and (3) space heating is produced by an under-floor series fan-powered terminal unit that draws air from the room rather than the ceiling plenum. Utilizing this system similar to the previous system not only results in saving energy by delivering air with a higher temperature than what is usually used in traditional cooling systems, but also creates higher occupant comfort by delivering air with lower speed than what is used in traditional systems, and where it is most effective.

The sources of energy consumption in this type of systems are the air handling unit supply fan motor input power, return fan motor input power, terminal unit fan motor input power, electric preheat strip (if it is used for freeze protection instead of hot water coil) in air handling unit and electric reheat strip (if it is used for dehumidification or heating instead of hot water coil). Duct air leakage, heat transfer from ducts connecting air handling unit to the under floor plenum, and efficiency

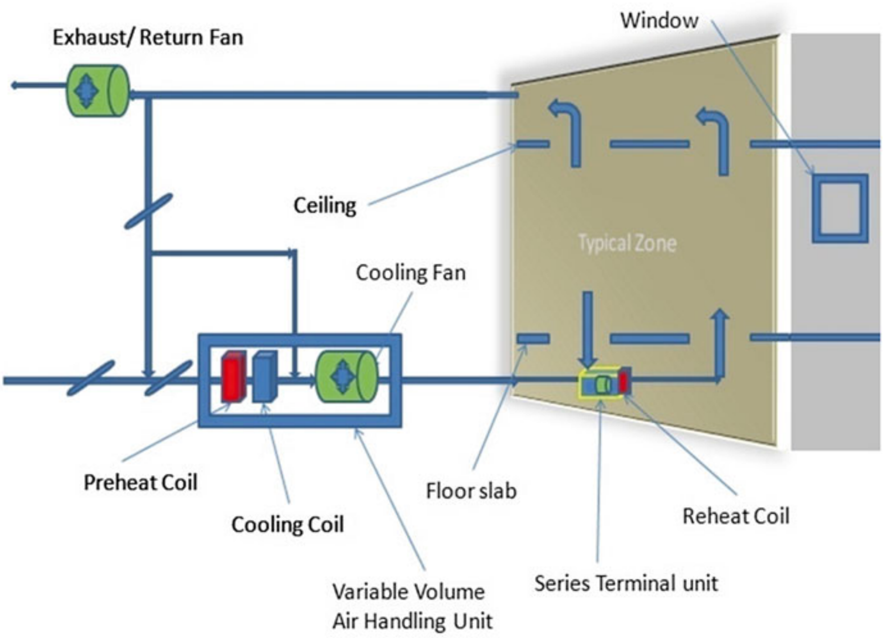

Fig. 8.13 Under-floor air distribution series, fan-powered VAV

loss in water coils are other sources that can indirectly increase the energy consumption of the system. The small energy consumed by low voltage power provided for control valves and dampers, and the power input to the variable frequency drives for supply and return fans that can be factored in supply and return fan consumption itself are the other sources of energy consumption.

8.13.4 UFAD VAV w/ Baseboard Heating

This system is similar to a variable air volume system with baseboard heaters except that (1) instead of using the duct for air delivery, it uses the under-floor plenum space, (2) there is an additional return-air bypass arrangement which is used to bypass return air to upstream of the fan in order to provide sufficient dehumidification when it is needed, without the need for a reheat coil.

Utilizing this system similar to the previous system not only results in saving energy by delivering air with a higher temperature than what is usually used in traditional cooling systems, but also creates higher occupant comfort by delivering air with lower speed than what is used in traditional systems, and where it is most effective.

The sources of energy consumption in this type of systems are the air handling unit supply fan motor input power, return fan motor input power, electric preheat strip (if it is used for freeze protection instead of hot water coil) in air handling unit and electric baseboard reheat unit (if it is used for dehumidification or heating instead of hot water coil). Duct air leakage, heat transfer from ducts connecting air handling unit to the under floor plenum, and efficiency loss in water coils are other sources that can indirectly increase the energy consumption of the system. The small energy consumed by low voltage power provided for control valves and dampers, and the power input to the variable frequency drives for supply and return fans that can be factored in supply and return fan consumption itself are the other sources of energy consumption.

8.13.5 Displacement Ventilation CV

Displacement ventilation originally was invented for industrial purposes such as using in welding industry in late 1970s. Since then its use has been increased in other industries and also in commercial and institutional in order to provide good indoor air quality along with means of saving energy. Utilizing this system similar to the under floor system not only results in saving energy by delivering air with a higher temperature than what is usually used in traditional cooling systems, but also creates higher occupant comfort by delivering air where it is most effective. In this system (Fig. 8.14) as low velocity air moves across the floor and as it gets in touch with heat sources (people, equipment, etc.) warms up and as a result of this higher temperature similar to what happens in the under floor system moves up by natural buoyancy and convection. Similar to under floor systems, when the room sensible load decreases the supply air temperature can be increased to even higher than 63 °F and therefore cooling consumption decreases even more.

Chen and Glicksman in their book (Chen and Glicksman 2003) represented the results of a CFD modeling for displacement ventilation system suitable for the US weather climate and showed with proper design these units can be utilized for cooling buildings with up to 40 Btu/h ft^2 cooling load.

The sources of energy consumption in this type of systems are the air handling unit supply fan motor input power, return fan motor input power, electric preheat strip (if it is used for freeze protection instead of hot water coil) in air handling unit and electric baseboard reheat unit (if it is used for dehumidification or heating instead of hot water coil). Duct air leakage, heat transfer from ducts connecting air handling unit to the sidewall diffuser, and efficiency loss in water coils are other sources that can indirectly increase the energy consumption of the system. The small energy consumed by low-voltage power provided for control valves and dampers is the other sources of energy consumption.

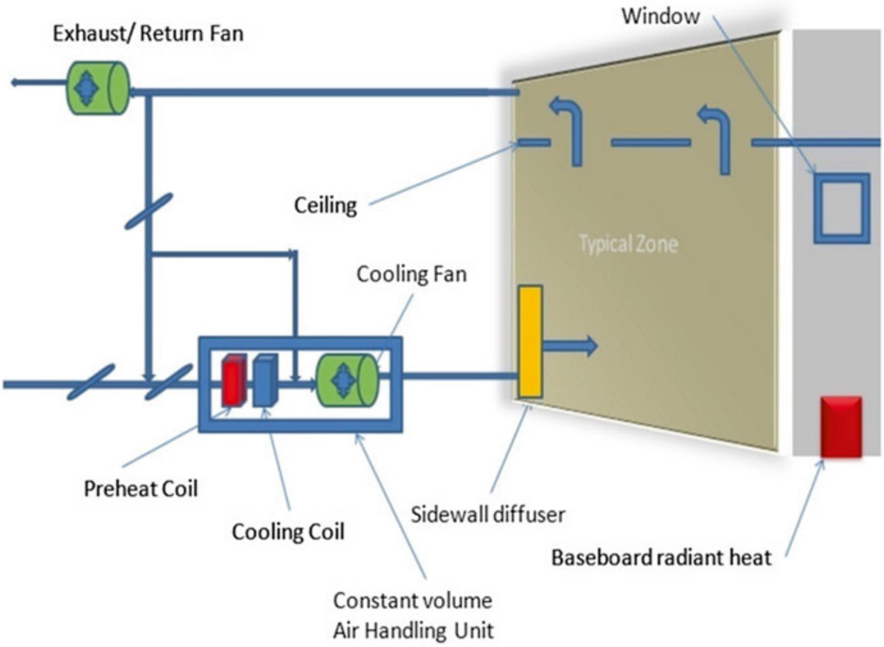

Fig. 8.14 Displacement ventilation CV

8.13.6 Displacement Ventilation VAV

This system (Fig. 8.15) is similar to a variable air volume system with baseboard heaters except that (1) instead of above the ceiling ducts the supply air is delivered via a large sidewall outlet near floor and (2) a return-air bypass arrangement is used to bypass return air to upstream of the fan in order to provide sufficient dehumidification when it is needed and without the need for reheat coil,

Utilizing this system similar to the previous system not only results in saving energy by delivering air with a higher temperature than what is usually used in traditional cooling systems, but also creates higher occupant comfort by delivering air where it is most effective. The terminal unit modulating damper controls the air entrance to the room based on the need specified by the room temperature sensor.

The sources of energy consumption in this type of systems are the air handling unit supply fan motor input power, return fan motor input power, electric preheat strip (if it is used for freeze protection instead of hot water coil) in air handling unit and electric baseboard reheat unit (if it is used for dehumidification or heating instead of hot water coil). Duct air leakage, heat transfer from ducts connecting air handling unit to the variable air volume unit and sidewall diffuser, and efficiency loss in water coils are other sources that can indirectly increase the energy consumption of the system. The small energy consumed by low voltage power provided

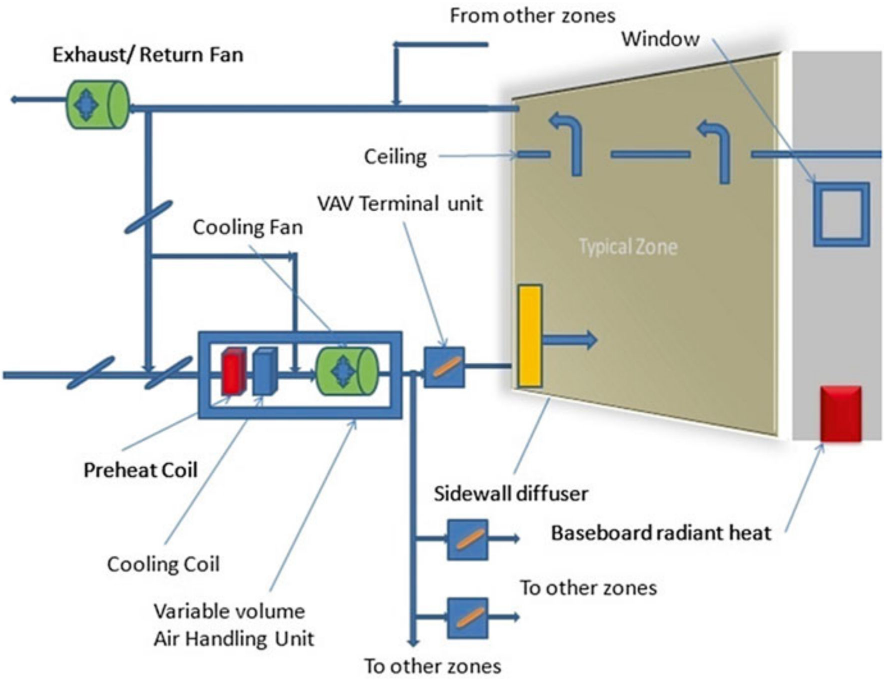

Fig. 8.15 Displacement ventilation VAV

for control valves and dampers, and the power input to the variable frequency drives for supply and return fans that can be factored in supply and return fan consumption itself are the other sources of energy consumption.

8.13.7 Displacement Ventilation w/ Passive Chilled Beams

In cooling mode, supply air through large side wall devices will be introduced to the room with a higher temperature (usually around 63 °F instead of normally 55 °F in regular systems). Air is introduced to the room as the space temperature sensor calls for cooling. If still there is need for further cooling, passive chilled beams in the ceiling will pick up the rest of the load. A return air bypass arrangement helps to provide dehumidification without the need for reheat.

The sources of energy consumption in this type of systems are the air handling unit supply fan motor input power, return fan motor input power, electric preheat strip (if it is used for freeze protection instead of hot water coil) in air handling unit and electric baseboard reheat unit (if it is used for dehumidification or heating instead of hot water coil). Duct air leakage, heat transfer from ducts connecting air handling unit to the sidewall diffuser, and efficiency loss in water coils are other sources that can indirectly increase the energy consumption of the system. The small energy consumed by low-voltage power provided for control valves and dampers, and the power input to the variable frequency drives for supply and return fans that can be factored in supply and return fan consumption itself are the other sources of energy consumption.

8.13.8 Active Chilled Beams

Chilled beam systems are usually used for cooling and ventilating spaces. Active chilled beams (Fig. 8.16) include a heat exchanger for cooling that can be used for heating if needed as well. If the internal humidity load of the space is not high, Chilled beam systems are very effective. Active chilled beams are connected to both the air handling supply air ductwork, and the chilled water system. The air handling unit supplies primary air into the various rooms through the chilled beams. As air supply is forced to the room through the chilled beam diffusers, it causes the induction of the room air back through the heat exchanger of the chilled beam. Two streams of the air then mix together, and the mixture goes over an auxiliary cooling

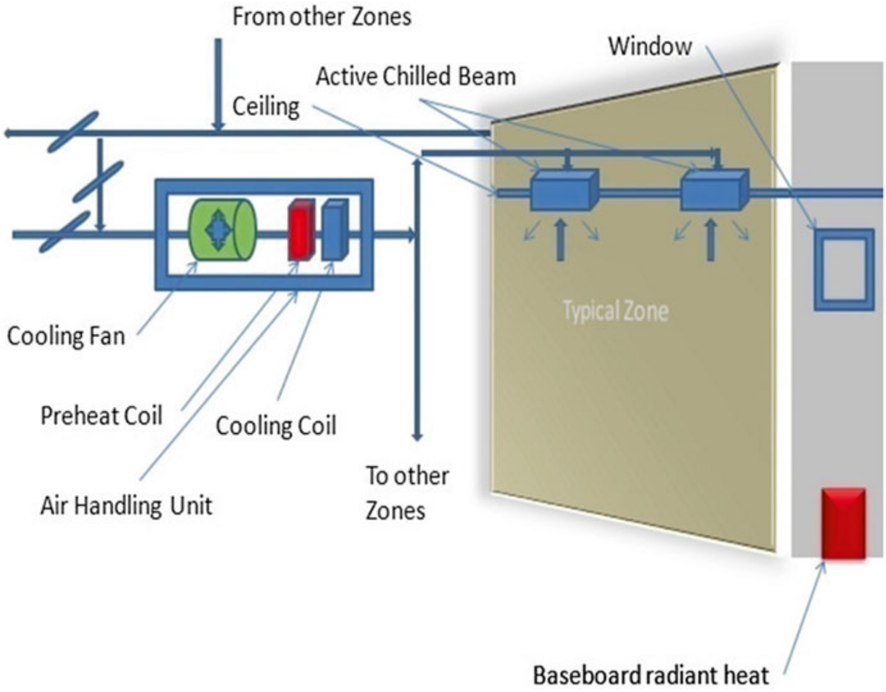

Fig. 8.16 Active chilled beams

coil (only if the main cooling is not sufficient) in the chilled beam and then enters the room to offset the room sensible load.

The chilled beam system provides excellent thermal comfort, energy conservation and efficient use of space due to high heat capacity of water used as heat transfer medium (Virta et al. 2003).

The sources of energy consumption in this type of systems are the air handling unit supply fan motor input power, return fan motor input power (if it is required), electric preheat strip (if it is used for freeze protection instead of hot water coil) in air handling unit and electric baseboard reheat unit (if it is used for dehumidification or heating instead of hot water coil).

Duct air leakage, heat transfer from ducts connecting air handling unit to the chilled beams, and efficiency loss in water coils are other sources that can indirectly increase the energy consumption of the system. The small energy consumed by low voltage power provided for control valves and dampers, and the power input to the variable frequency drives for supply and return fans that can be factored in supply and return fan consumption itself are the other sources of energy consumption.

8.13.9 Hybrid Ventilation

A hybrid ventilation system is a system that it is designed and has the potential to be switched between the mechanical and natural ventilation modes. Before going any further, it should be comprehended that the effectiveness of a hybrid system has close dependency on the outdoor climate surrounding the building. Therefore selecting the proper locations for installing a hybrid ventilation system is one of the most important prerequisites of a successful project.

The obvious difference between a mechanical ventilation system and a natural ventilation system is the use of a mechanically operating device (usually a fan) that facilitates the flow of the required outdoor air into and out of the building in case of the mechanical ventilation system. In case of the natural ventilation system, building relies solely on means of directing the outdoor air into and out of the building, such as operable windows.

The important point to remember is that in a hybrid system as a support to the shortfalls of the natural ventilation system a mechanical ventilation system can be supplemented any time during or after the original design was done. To the contrary it is not simply possible to enhance an existing mechanically ventilated building with natural ventilation supporting system. A successful natural ventilation system demands utilization of envelope elements such as openings and construction masses which are part of the structure of the building that are not simply reconfigurable after the original design is completed. Therefore to design a successful hybrid ventilated system it is crucial to design the (hybrid) ventilation system as part of the original building design itself.

In general, natural ventilation systems can be categorized into two types of wind-driven and buoyancy-driven systems. As it appears from the names of these two

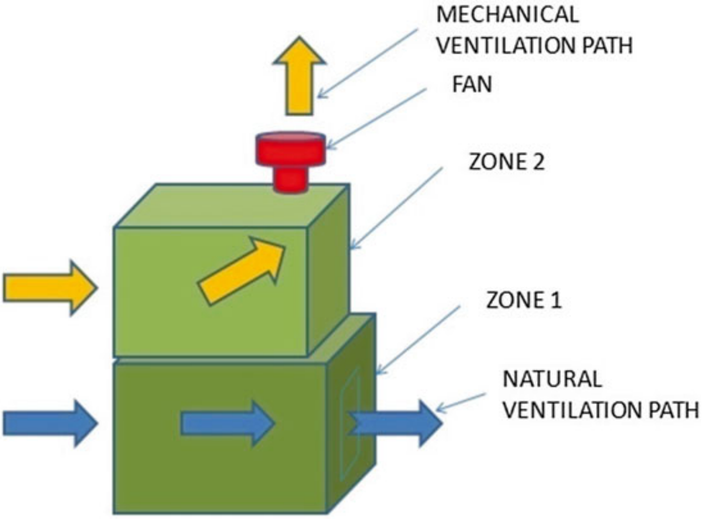

Fig. 8.17 Independent natural and mechanical ventilation

types, the first natural ventilation system relies on the wind effects to create the required ventilation inside the building, while the second natural ventilation system relies on the temperature difference between the inside and outdoor air which creates the resultant air movement inside the building.

Most of the hybrid ventilated building designs fall into one of the following three categories: independent natural and mechanical systems (Fig. 8.17), mechanically assisted natural ventilation systems (Fig. 8.18), and naturally assisted mechanical systems (Fig. 8.19).

In an independent natural and mechanical system the building has two completely independent systems. The control system either utilizes one system for a task in the building and the other system for another task in the building (e.g., mechanical ventilation system for the summer and winter seasons and natural ventilation system for spring and fall seasons), or switches between the modes in different occasions for the same task in the building (e.g., mechanical ventilation system for occupied hours and natural ventilation system for unoccupied hours in same day).

In a mechanically assisted natural ventilation system, the basic system which is serving the building is a natural ventilation system. During the periods of time that only by natural ventilation the required results are not achievable a mechanical system (usually a supply or exhaust fan) improves the required pressure difference to facilitate proper ventilation.

Finally a naturally assisted mechanical ventilation system is designed based on a main mechanical ventilation system with very low pressure drop, where stack effects inside or wind effects outside of the building can assist the ventilation process by generating the majority of the required pressure for the air movement.

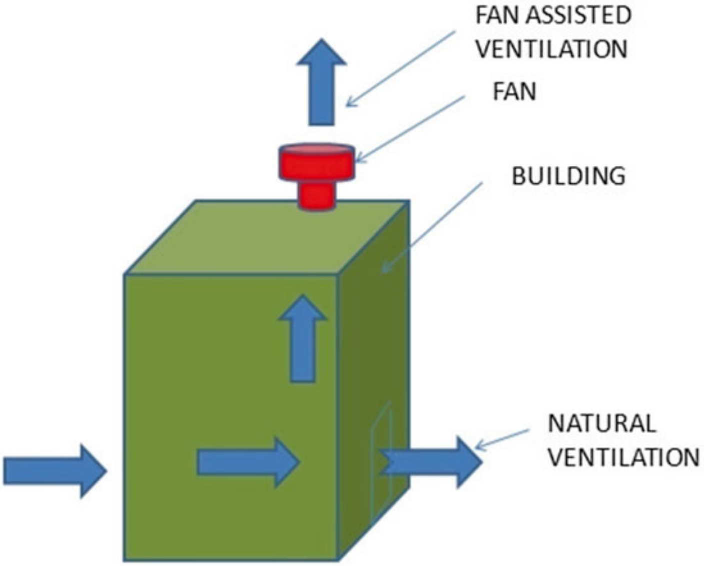

Fig. 8.18 Fan assisted natural ventilation

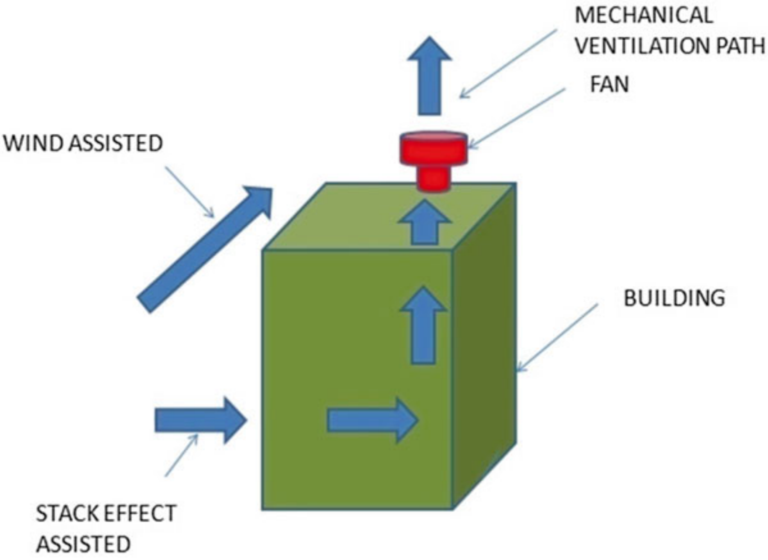

Fig. 8.19 Naturally assisted mechanical ventilation

The following conditions in the building generally decrease the chances of efficiently utilizing the natural ventilation mode in a hybrid ventilation system. (1) sub-standard envelope construction, tightness, insulation and thermal bridges, (2) considerable sources of pollution inside or outside of the building, (3) outdoor noise pollution, (4) undesirable wind effects, and (5) very large interior spaces.

And the following conditions in the building generally increase the chances of efficiently utilizing the natural ventilation mode in a hybrid ventilation system: (1) larger rooms with high ceilings, (2) available clean outdoor air, (3) possibility of use of outdoor air openings without risking the security of the building or increasing the noise pollution risk, (4) and exposed thermal mass in the building structure.

A thorough discussion about advanced hybrid ventilation technologies along with useful case studies can be found in Heiselberg's research "Principles of Hybrid Ventilation" (Heiselberg 2002).

8.14 HVAC System Selection

Selecting the proper system for the application in hand has been subject of many discussions, and different methods have been proposed to improve the potential of the best possible system selection in the industry. Relying on expertise of the experienced engineers in the firms has been the first source of influence on selection of the proper system for designing the projects since early years of modern building system design in different engineering firms. In this method the most experienced engineer of the design team due to his/her experience suggests the proper system that could satisfy the required conditions for the application. The main problem with this method is that each experienced engineer and for that reason each designing firm has its own expertise in design of some specific type of systems, which tends to influence how the proper system has been selected for the application. This helps to avoid extra time and money required for research, learning and execution to the perfection of the other possible systems. Of course this method may results in a very high quality building system design that in exchange will protect the design team from the possible mal-operation of the building HVAC system and therefore the possible future lawsuits. But the negative side of using this method can be the missing opportunity for designing of even better and more efficient systems and saving money and energy that could come from a better system choice.

Creating matrices that compare and grade the positive and negative effects of important characteristics of each alternative system has been offered by different resources as well.

This procedure usually starts with the design engineer selection of two or three proper systems for the design application. His next step is to create a list of the factors that may have significant importance on his decision for selecting the proper system, and assign two numeric values (usually between 1–10 and 1–100) to each factor regarding each alternative system and its degree of importance based on his/her judgment. Finally a weighted average of all these factors will represent the overall best alternative system to be selected as the system type.

This method has its obvious advantages over the previous method since it generates a comparison among the possible alternatives, and provides the designer with a quantitative measure for this evaluation and comparison. Another important benefit of this method is that it can force the designer to think about important parameters and factors that could affect the final product in advance.

In past two decades ASHRAE standard 90.1 (ASHRAE 2013) has presented a comparison method mostly based on energy modeling simulation results to enhance the system selection procedure. This standard represents a base system for each type of building application and the designer has to perform two separate energy consumption simulations and then compare the results of his design simulation against the base system simulation. If the design building/system energy consumption shows to be lower than the one from the base building/system, then the selected system is acceptable from the energy standard point of view. The outcome of this exercise is the ground for gaining points in building energy efficiency scoring systems such as LEED.

A possible alternative method (I have described the structure of such method in Chap. 13) can be defined as performing multiple simulations for larger numbers of systems and evaluation of the results in a risk based methodology. In this method the designer should perform multiple risk-based simulations (not a basic deterministic type simulation) and compares the results before selection of the most energy conscious system for the design application. By utilizing such system one can present the advantages and disadvantages of each possible system in a probabilistic language.

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Chapter 9
Building Automatic Controls

9.1 Importance of Building Automatic Controls

Along with proper system selection, a well-planned control system is one of the most effective design elements that can contribute to proper functioning and also saving energy during the building operations. A well-planned control system can make all the building system elements to function close to their highest possible efficiency level when they are supposed to, and preserve energy when there is an opportunity for energy saving in the system throughout the time. If the building control system is designed properly it acts as a knowledgeable and strong brain and nerve network that receives messages, thinks through them, and selects the proper responses and informs the targeted muscles (element) to act properly and in a timely manner according to the selected response. Therefore understanding the structure of the building control system and also recognizing the important role that automatic control and proper use of this effective tool can have, will be essential for satisfying the building energy saving goals. In this section after a short introduction about how a communication network is structured and works, I will briefly describe the necessary elements and duties of the building automatic control system components. I will also discuss the importance of a properly written sequence of operation for the building equipment later in this chapter. For a thorough discussion about specifying direct digital control system refer to ASHRAE Guideline—Specifying Direct Digital Control Systems.

9.2 A Brief Overview of Communication Systems

In networking environment, an open system interconnection (OSI) model is a frame that is used for standardization of functions of communication systems. Therefore to understand how a network communication works, it is necessary to understand

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the concepts and functions defined in OSI model. Under OSI model, a typical networking system is defined to be built from seven major layers. These layers in order from bottom to top are (1) physical layer, (2) data link layer, (3) network layer, (4) transport layer, (5) session layer, (6) presentation layer, and (7) application layer. Network structure is built in such manner that each layer and its components serve the layers above it and being served by layers below it. First three layers (physical, data link, and network) are known as media layers and their data units are, bit, frame and packet (datagram) respectively. Last four layers are host layers (transport, session, presentation, and application) and the types of their data units are segments (transport), and data (session, presentation, and application). Starting from bottom level, function of the first layer is signal and binary transmission, while the second layer function is physical addressing or what it usually is known as switching. The physical layer defines the electrical and physical specifications for devices such as fiber optical cables that are responsible for transmission of data through this physical medium to the destination physical layer. The data link layer defines the procedural method of data transferring between elements in the (same) network. This layer (data link layer) is the layer that transfers data between nodes in a wide area network (WAN) or local area network (LAN). This layer is subdivided to two sublayers of logic link control (LLC) and media access control (MAC). In building controls operation the network address of each sensor or actuator operating in the building resides in (MAC) layer, and therefore this layer is responsible for receiving and sending signals from and to the sensors and actuators in the system with individual network addresses.

Function of the third layer (network layer) is logical addressing. This layer provides the means of transferring data between a host on one network to destination host on a different network. Function of the fourth layer (transport layer) is the data flow control. The main responsibility of this layer is controlling reliability and providing an error-free data transfer between the end users. Responsibility of the fifth layer (session layer) is managing sessions between the applications, and responsibility of the sixth layer (presentation) is data presentation and converting machine dependent information to machine independent information. Finally the seventh layer (application) interacts with software applications to define functions such as identifying and synchronizing communication.

As an example the data exchange between two network systems (network one and network two) each made of its own OSI defined seven layers should basically follow the proceeding path. The operator at network one via a key board and interface at application layer generates a data that will travel down the seven layers on network one and at each layer the required formatting and addressing data will be added to the data until at the lowest level or layer one of network one it is ready to be delivered to network two. Respectively, network two will receive the data through its lowest layer and send the data up through its OSI defined seven layers in which at each layer formatting and addressing data added in network one will be read and as a result directs the final data correctly to the top layer (application layer) at network two. At this time the operator at network two is able to see the data as it was sent by the operator at network one, and then provide his own response through a similar path.

Somewhat similar to this process in a typical building control system, each sensor which has its own specific network address generates a signal sensed from the field and sends it to data link layer at MAC sub layer of the building control system. MAC sub-layer receives the data and sends it up through the different layers to the application layer where the direct digital control software is resides. In application layer, the received signal from MAC layer will be compared against a preprogrammed desired quantity (set point) and based on the degree of deviation of the received data from the preprogrammed set point data a command will be generated that will travel down the network layers and to the MAC layer. MAC layer then directs the response to the proper actuator (proper address) and cause an adjustment at a control device such as a damper or a valve in which as a result attempts to provide the proper condition in the space in which the original data was sensed via local sensor.

Another communication protocol which is more useful in connecting hosts to internet is called Transmission Control Protocol/Internet Protocol (TCP/IP). This protocol generally is used by Internet applications to connect different devices to a common network (Internet). The difference in structure of TCP/IP model and OSI model is that in TCP/IP a four layer model instead of the seven layer model developed in OSI model is used. TCP/IP layers are (1) link layer (similar to physical and data link layers in OSI model), Internet layer (similar to network layer in OSI model), transport layer (similar to transport layer in OSI model), and application layer (similar to session, presentation, and application layers in OSI model). It should be noted that OSI model is basically a theoretical reference model, while TCP/IP is a practical model that is developed around the Internet functions.

9.3 Control Algorithms

Control algorithms generally are defined to be one of proportional (P), proportional plus integral (PI), and proportional, plus integral plus derivative (PID). To better understand how each of these logics act, imagine you are driving your car on a road with a speed of 45 miles per hour, which is your desired speed (set point) as well. Originally you are satisfied with the car speed, until you reach an uphill section of the road, and your car speed drops to 40 miles per hour. At the moment you recognize that your speed has dropped you push more on the gas pedal which increases your speed which after some time reaches to 47 miles per hour. Since you want to keep the set point (45 miles per hour) speed, you will decrease the pressure on the gas pedal and the car speed drops to 44 miles per hour. You will continue this increasing and decreasing pressure on the gas pedal until you reach the desired 45 miles per hour again.

In each instant you are fighting to overcome the discrepancies from the desired speed set point with your controlling actions. Discrepancies at each instance are the sum of (1) how much the real speed deviates from the set point (proportional), (2) a weighted average of the undesired speeds and the time spent in these speeds from the last time at set point (integrated), and (3) how fast (steep) you are approaching or going away from the set point (derivative).

If you imagine your brain is similar with the direct digital controller of the HVAC system, the combination of your foot and the gas pedal as the actuator, the odometer as the sensor, and the car speed with any one of HVAC system characteristics, such as temperature or pressure, you can relate to and understand how the HVAC control logic works. For example as due to additional load in the space, the room temperature deviates from the set point of 75 °F sensed by the temperature sensor, the direct digital controller issues a command that modulates the chilled water valve on the cooling coil of the air handling unit. This action generates some cooling that after a few times repeating of this routine of measuring the temperature and modulating the cooling valve position, brings the space air temperature back to 75 °F again. Here the discrepancies at each instance are the sum of (1) how much the real temperature deviates from the set point (proportional), (2) a weighted average of the undesired temperatures and the time spent in these temperatures form the last time at set point (integrated), and (3) how fast (steep) the system is approaching or going away from the set point (derivative).

In HVAC industry, most of the controls that are utilized are capable of performing all three algorithms, but due to nature of the systems and lack of need for very fast response, usually the derivate logic is not going to be used (ASHRAE 2011).

9.4 Direct Digital Control

The basic and yet the most important benefit of a Direct Digital Control (DDC) system in a building is its capability to optimize the operation of the HVAC system by conducting the system elements to perform in harmony and near their highest possible efficiency levels and also directing the different system components to operate only when they are needed to do so. This has a major impact on the level of energy efficiency of the building and therefore prevents energy wasting during the system operations. In addition since the DDC system is a programmable system, it not only provides the capability of recording the environment and system data, and changing the components and set points of the system if the recorded trend shows the presence of abnormality in the past, but also provides programming change capability if the desired condition of the targeted venue changes later on. A sample of the first condition is when an owner by referring to and reviewing the recorded temperature log in a specific room figures out that specific space is continuously slightly hotter than the expected temperature set-point and after investigation finds out the terminal unit damper serving that space is not functioning properly, and therefore attempts to fix the problem. On the other hand a sample of the second condition could be seen when the owner of a museum decides to change the function of a space from a function requiring little to no humidity control to a space that requires tight humidity control such as changing the function of an office space in the museum to a storage space for storing artwork.

Another contribution of a DDC system in addition to controlling the HVAC system operation is that a DDC system can also facilitate controlling non-HVAC systems in the building such as lighting system.

Generally the building DDC system is a combination of software and hardware (micro-processor-based controllers and electronic sensors) that is capable of continuously monitoring and maintaining different spaces desired temperatures, pressures, humidity, air quality, energy management, etc. inside the building. A collection of binary (on/off), analog (variable) or pulse accumulation signals from the sensors throughout the building and its systems are delivered to the DDC system. These delivered data to the direct digital control system are known as DDC system inputs. These signals then will be compared against the preprogrammed values for each space or location conditions through Proportional, Integral, Derivative (PID) algorithms and the binary, analog or tri-state output signals then will be sent to the actuators at each part of the HVAC system (or other building systems) to change and adjust the current conditions and make the desired conditions at each space or location available.

Generally the most important control components of a DDC system structure are building controllers, custom application controllers, application specific controllers, communication gateways, system integrator, routers, I(nput)/O(utput) devices, auxiliary devices, and operator interfaces.

Typically the direct digital control network structure or architecture is the way that network components have been arranged in respect to each other and interact together. Communication between the network elements is done by wires (physical media) and communication buses (data link layer). In building automatic controls, communication buses have responsibility to connect workstations together, controllers to workstations and finally lower level controllers to each other. At the top of the structure the building controller is located that is the main programmable general purpose controller. This main controller then communicates with a network of lower level controllers to manage the building systems operations. The lower level controllers are known as either custom application or application specific controllers. A custom application controller is a controller that generally controls specific complex equipment such as air handling units or chillers, and an application-specific controller is generally a manufacturer's preprogrammed controller that is used for controlling less complicated equipment such as VAV (variable air volume) boxes and other simple equipment.

A proprietary network is designed and built by a single manufacture; therefore when the size of the DDC system is not large and there is no future plan for the system expansion, performs the daily tasks more easily and less costly. On the other hand, an open network can be arranged to work with different provider's systems, and therefore more complex systems can be designed and installed. Current prevailing trend of control design is using open systems due to its higher flexibility. As a result the most common case of integration between these two networking systems occurs when the existing system is an old system working with a proprietary system, and the new expansion is designed to work with an open network. In this case a communication gateway shall be installed to relate two networks together.

Communication gateways are the tools that do the translation between two different communication protocols. In addition to translation between the proprietary and open systems, it also can be used to translate between equipment designed with different manufacturers inside a new open system. The faster and the better this translation is executed the higher is the interoperability of the communication gateway.

Other notable elements in a control network system are local area network (LAN) that is a system for sharing information between different DDC systems, system integrator that ensures the information exchange between the two networks through the communication gateway is being done precisely, and routers that are used to convert data link layer protocols and do not require to translate between languages.

DDC controllers interact with different elements of the system through inputs and outputs signals that receive information from sensors and send command to actuators respectively. Auxiliary elements are devices such as control valves and dampers, and operator interface is a software package that monitors and controls the operation of the system.

9.5 Sequence of Operation

Since the control system designer, system installer, commissioning agent that overview the installation of the system and the building engineering staff whom after the delivery of the building overviews the daily operation of the building are different people, and since controlling the building operation is an ongoing procedure that last throughout the life of the building, there is a vital need for the designer to clearly describe what his targets of system functionality under different conditions and situations are. This helps the control contractor to install the system and program it properly, commissioning agent to point out the diversions of the installation versus the designer's plan more easily, and building staff to maintain and troubleshoot the system as per designer's guidelines without need for any kind of guessing. This is usually done with a well written sequence of operation and schematic control diagram as part of the design document, in which the designer depicts and describes his expectations of functionality of the system as the building external and internal conditions change.

In writing a sequence of operation, the designer should be very specific and detail-oriented, describes all the possible conditions, and answers all the probable questions regarding the system operation under different conditions, in order to simplify the understanding and therefore interaction of the other involved individuals as described above with the control system. In pursuing this goal the control system designers usually divide the whole HVAC system into its smaller entities such as chillers, boilers, air handling units, fan coil units, etc., and thoroughly describes their expectations of each equipment functionality. Generally the target of a HVAC control system is to monitor or control parameters such as temperature, pressure, humidity, flow, carbon dioxide level, and filter pressure drop. Therefore a complete set of guidelines should be provided to define the desired set points of each of these parameters at each location, each space, and at each time. Each set point should be presented by the acceptable parameter range. A typical sequence of control for a space temperature can be written as: “The control system shall maintain temperature of the space ‘xyz’ at 75 ± 2 °F at all time” and a typical sequence of control for a space carbon dioxide level can be written as: “The control system shall maintain carbon dioxide level in space ‘abc’ at a maximum value of 1000 ± 100 parts per million (ppm) at all time.”

A generic, simple, and step-by-step sequence of operations for a typical variable volume air handling unit with water cooling and heating coils can be written as follows:

- Typical sequence of operation for starting and stopping a variable volume air handling unit system: The direct digital control system shall automatically start and stop the air handling unit whenever the designated operation switch is in the automatic position, and allows for manually starting and stopping the air handling unit whenever this switch is in hand position (this allows for both automatic and manual start and stop of the system).
- Typical sequence of operation for opening and closing dampers: The direct digital control system shall open the return, minimum outside air and smoke dampers before the air handling unit fan is started. (This control allows for a safe operation of the system so the fan does not operate against dampers that are closed, and cause any damage to the ductwork network or fan.)
- Typical sequence of operation for morning warm-up: When the system is set for morning warm-up mode, the direct digital control system shall run the air handling unit and close the minimum and maximum outside air and relief dampers and the air handling unit chilled water valve. The direct digital control system shall modulate the terminal units air valves to fully open position, and modulate the heating coil valves to provide hot supply air until space temperature rises above a warm-up mode set point. (This control allows the space temperature to reach an acceptable level before the scheduled time for the occupant’s arrival. Therefore when the early crowed enter the building do not feel cold and uncomfortable.)
- Typical sequence of operation for night low limit mode (NLL): On a request for night low limit operation from minimum five VAV zones (adjustable), the direct digital control system shall enable the supply fan variable frequency drive (VFD) and supply air temperature controls. During NLL mode the direct digital control system shall set the supply air temperature set-point to the warm-up supply air temperature set-point (e.g. 75 °F, adjustable). When the number of VAV zones requesting NLL drops below the minimum required VAV zones, or occupied mode becomes active, the direct digital control system shall disable NLL. (This control prevents the building temperature during the off hours drops below a minimum allowable setting.)
- Typical sequence of operation for night high limit mode (NHL): On a request for night high limit operation from a minimum five VAV zones (adjustable), the direct digital control system shall enable the supply fan VFD and supply air temperature controls. When the number of VAV zones requesting NHL drops below

the minimum required VAV zones, or occupied mode becomes active, the direct digital control system shall disable NHL. (This control prevents the building temperature during the off hours of the building moves above a maximum allowable setting.)

- Typical sequence of operation for maintaining air handling unit discharge temperature: The direct digital control system shall modulate the chilled water valve to maintain air handling unit discharge air temperature set point. The direct digital control system shall reset the discharge temperature set point upward on a fall in space temperature below 70 °F (adjustable) (this control allows the system to deliver air at a preset value (typically 55 °F) and when possibility arises, to increase this set-point to higher temperatures gradually in order to save energy).
- Typical sequence of operation for maintaining duct static pressure: The DDC system shall modulate the variable frequency drive to maintain a pre-set duct static pressure set point at all time (this control allows the system to run with enough capacity in order to keep a pre-set static pressure level in duct and therefore proper amount of air be delivered to each space at all time).
- Typical sequence of operation for fan high pressure safety: Upon receiving a signal of an air pressure of at least 5 in. of water column (adjustable) in supply duct, the direct digital control system through a high-pressure switch located in the supply air ductwork shall stop the fan (this control prevents the system from over-pressuring and damaging the ductwork).
- Typical sequence of operation for maintaining mixing plenum static pressure: The direct digital control system shall modulate the return air damper to maintain mixing plenum static pressure and minimum required outside air quantity. This static pressure shall be measured by a static pressure sensor installed inside the mixed air plenum and adjusted at time of balancing the system. (A more accurate and also more expensive method is installing an air measuring station in the minimum outside air path to deliver the exact quantity of required minimum outside air at all time.) (This control allows the proper amount of minimum outdoor air at all times be introduced to the system).
- Typical sequence of operation for maintaining the preheat coil discharge temperature (freeze protection): The direct digital control system shall modulate the preheat coil hot water valve to maintain coil discharge temperature set-point. This temperature shall be sensed by an averaging temperature sensor (at all time, even during the system shutdown) which is located downstream of the preheat coil (this control allows the air temperature leaving the preheat coil and passing over the cooling coil maintain enough temperature and therefore prevent freezing of the cooling coil).
- Typical sequence of operation for airside economizer mode: The direct digital control system shall initiate economizer mode operation when the outdoor air temperature (dry bulb) drops below a set point, approximately (65 °F adjustable). When the air handling unit is operating in economizer mode, the direct digital control system shall modulate the relief and maximum outside air dampers to maintain air handling unit discharge air temperature set-point. When the maximum outside air damper is fully open and the discharge air temperature set point

still is not satisfied, the direct digital control system shall modulate the chilled water valve open to satisfy the space demand. Upon receiving a command from a low limit control with averaging element which senses temperature of the air entering the coils, the direct digital control system shall override other damper controls, and modulate the maximum outside air, and relief dampers to limit mixed air temperature to (45 °F adjustable) minimum (this control allows the air handling unit takes advantage of cold enough outdoor air when it is available and provides a cooling air into the space without need for utilizing cooling coil).

- Typical sequence of operation for maintaining air entering cooling coil: The direct digital control system shall utilize a separate low limit safety which senses the temperature of the air entering the cooling coil and is set at 40 °F (adjustable) to stop the fan (this is another control to protect the cooling coil from freezing).
- Typical sequence of operation on power interruption: When the power interrupts or fan shuts down, the direct digital control system shall close the minimum and maximum outside air, relief, smoke and return dampers, and chilled water and hot water valves. The direct digital control system also shall stop the terminal units and close their associated heating coils valves (this control protects the system against unexpected conditions where the power supply to the system is interrupted or the system is shut down for maintenance).
- Typical sequence of operation for variable volume terminal units: The direct digital control system shall modulate the primary air valve of each variable volume air terminal unit between its designated minimum and maximum quantities to maintain space temperature (this control allows proper air delivery and also required minimum outdoor air through the primary air valve minimum setting to each individual space).
- Typical sequence of operation for variable volume-reheat terminal units: The direct digital control system shall modulate the primary air valve of each variable volume air terminal between its designated minimum and maximum quantities to maintain space temperature. When the space temperature drops below a set point the direct digital control system shall modulate the primary air valve to its minimum setting and shall modulate the hot water control valve to maintain space temperature (72 °F adjustable) (this control allows proper air delivery and also required minimum outdoor air through the primary air valve minimum setting to each individual space).
- Typical sequence of operation for parallel fan powered terminal units: The direct digital control system shall modulate the primary air valve of each parallel fan powered variable volume air terminal between its designated minimum and maximum quantities to maintain space temperature. When the space temperature drops below a set-point the direct digital control system shall modulate the primary air valve down to its minimum setting, start the fan, and modulate the hot water control valve to maintain space temperature (72 °F adjustable) (this control allows a variable flow capacity with proper air temperature delivery to each individual space. This airflow will be between the maximum design airflow and minimum required outdoor airflow which is usually called primary air).

- Typical sequence of operation for series fan powered terminal units: The direct digital control shall start the fan and shall modulate the primary air valve of each series fan powered variable volume air terminal between its designated minimum and maximum quantities to maintain space temperature. When the space temperature drops below a set point the direct digital control system shall modulate the primary air valve down to its minimum setting, and modulate the hot water control valve to maintain space temperature 72 °F (adjustable) (this control allows a constant airflow with proper air temperature delivery to each individual space. This system is usually used for high occupancy spaces such as conference rooms in office buildings).
- Typical sequence of operation for smoke detectors: If smoke detectors in the supply and return air ducts sense the heat or smoke presence the direct digital control system shall automatically shut down the air handling unit fan (this control prevents the spread of smoke to the different spaces through air handling unit fan).
- Typical sequence of operation for fan alarm: The direct digital control system shall generate an alarm and display a warning message in operator's workstation if the fan is commanded to operate and status is not proven after more than 15 s (this control sends an alarm to warn the operator that a malfunction in the system has happened and requires attention).
- Typical sequence of operation for supply air temperature alarm: The direct digital control system shall generate an alarm and display a warning message in operator's workstation if the supply fan is proven running and supply air temperature is 6 °F (adjustable) above or below its set point for at least 15 min (this control sends an alarm to warn the operator that a malfunction in the system has happened and requires attention).
- Typical sequence of operation for heating coil discharge temperature alarm: The direct digital control system shall generate an alarm and display a warning message in operator's workstation if the heating coil discharge air temperature is 6 °F (adjustable) below its set point for a continuous period of 15 min (this control sends an alarm to warn the operator that a malfunction in the system has happened and requires attention).
- Typical sequence of operation for heating valve leak alarm: The direct digital control system shall generate an alarm and display a warning message in operator's workstation if the heating coil valve is proven closed and the heating coil discharge temperature is at least 2 °F (adjustable) above the heating coil intake temperature for a period of time of at least 30 min (adjustable) continuously (this control sends an alarm to warn the operator that a malfunction in the system has happened and requires attention).
- Typical sequence of operation for cooling capacity shortage alarm: The direct digital control system shall generate an alarm and display a warning message in operator's workstation if the cooling coil valve is in fully open condition continuously for at least 1 h (adjustable) (this control sends an alarm to warn the operator that a malfunction in the system has happened and requires attention).
- Typical sequence of operation for cooling valve leak alarm: The direct digital control system shall generate an alarm and display a warning message in operator's

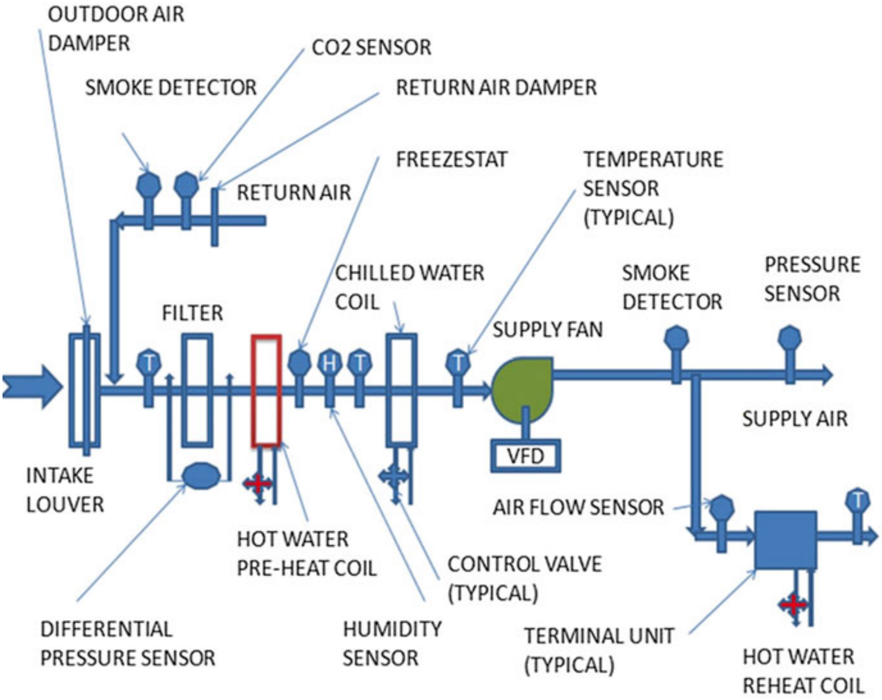

Fig. 9.1 Control schematics for an air handling unit

workstation if the cooling coil is proven closed and the cooling coil discharge temperature is at least 2 °F (adjustable) below the cooling coil intake temperature for a period of time of at least 30 min (adjustable) continuously (this control sends an alarm to warn the operator that a malfunction in the system has happened and requires attention).

In addition to sequence of operation, a well-drawn schematic control diagram and an Input/Output summary can help to transfer ideas of the control designer to control installers and commissioning agents as well as building engineering personnel.

A schematic control diagram (Fig. 9.1) depicts the physical location of different elements in each one of the equipment in an orderly manner and shows each element's communication with the central direct digital control system. For example a typical schematic diagram of an air handling unit should show the path of air movement through the outdoor and return air dampers, filter, preheat coil, cooling coil, fan, discharge plenum, humidifier, and space terminal units. In the path from each element to the next a group of desired control sensors such as temperature and humidity sensors will be shown to be installed which their main responsibility is to sense the condition at that specific location and communicate that with the direct digital control controller. Also location of the actuators which upon receiving commands from the direct digital control central controller will be physically operating to change the flow of the medium in elements such as chilled water coil control valve, and fan variable frequency drive will be specified.

Depending on the type and direction of communication with the central direct digital control system each element is marked with input and output and types of input and output designations such as Analog Input (AI) or Digital Output (DO). Any signal entering the direct digital control system controller is an input, and any signal that leaves the direct digital control system controller is an output.

For a typical variable volume air handling unit with hot water preheat coil and chilled water cooling coil a typical list and type of the input and output points (I/O Summary) can be described as follows:

Analog inputs:

- Air handling unit discharge temperature (temperature; °F)
- Cooling coil entering air temperature (temperature; °F)
- Cooling coil leaving air temperature (temperature; °F)
- Space temperature (temperature; °F)
- Space humidity (humidity)
- Supply duct static pressure (pressure; inch of water gauge)
- Outdoor temperature (temperature; °F)
- Outdoor humidity (humidity)
- Return air CO_2 level (part per million)
- Critical space CO_2 level (part per million)
- Chilled water valve actuator position (% of full open)
- Preheat hot water valve actuator position (% of full open)
- Minimum outside air damper actuator position (% of full open)
- Maximum outside air damper actuator position (% of full open)
- Relief damper actuator position (% of full open)
- Fan variable frequency drive speed (speed; rounds per minute)
- System supply airflow rate (flow; cubic feet per minute)
- Terminal unit flow rate (flow; cubic feet per minute)
- Minimum outdoor airflow (flow; cubic feet per minute)

Digital Inputs:

- Supply fan proof of operation (on-off)
- Filter status (clean-dirty)
- Humidifier proof of operation (on-off)
- Selector switch status (on-off)
- Override switch status (on-off)
- Low temperature limit status (yes-no)
- Mixing box static safety status (on-off)
- Discharge static safety status (on-off)
- Return static safety status (on-off)
- Power status (on-off)
- Preheat hot water pump proof of operation (on-off)
- Smoke damper actuator position (on-off)

Analog outputs:

- Economizer damper command (% of full open)
- Relief damper command (% of full open)
- Face and bypass damper command (% of full open)
- Chilled water valve command (% of full open)
- Humidifier valve command (% of full open)
- Variable frequency drive speed command (% of full speed)
- Preheat hot water valve command (% of full open)

Digital outputs:

- Supply fan start/stop (on-off)
- Variable frequency drive enable/disable (on-off)
- Humidifier shutdown (on-off)
- Preheat hot water pump command (on-off)
- Power status (on-off)

In addition to these inputs and outputs, the direct digital control system will generate required software alarms and displays them in the operator's workstation.

Similar sequence of operations and input/output summaries need to be generated for all other equipment in the system such as chilled water and hot water plants, exhaust air system, etc.

9.6 Advanced Control Strategies for Energy Saving

9.6.1 Demand Ventilation Control

This control allows the system to be capable of operating with a level of outside air even less than minimum outdoor air required calculated by governing standards. In this design CO_2 sensors that are located strategically throughout the building to sense and measure the real time part per million (ppm) of CO_2, specifically in crowded spaces of the building, and if this value is below an acceptable threshold, allows the direct digital control system to decrease the minimum outdoor air level. This strategy is a very effective measure for saving energy.

9.6.2 Optimum System Start or Stop

It is a common practice to set the controls of the building to switch the air conditioning system from unoccupied mode to occupied mode earlier than expected occupancy time, in order to provide a comfortable condition for the occupants as they arrive to the building early in the morning, or early Monday mornings. Based on time of early occupancy of the building, outdoor conditions, and the thermal characteristics of the building construction material a well-designed control system can configure the latest possible time for switching to the occupied mode in order to save energy by not engaging the air conditioning system when it is not required yet. Stopping the air conditioning system early enough before the end of scheduled occupancy period in the evening in order to save energy without sacrificing the occupants comfort also falls under the same control strategy.

9.6.3 Fan-Pressure Optimization for VAV Systems

Implementing this control strategy makes the system to continuously monitor all the different zones load and decrease the air handling unit fan speed enough to only overcome the pressure required for keeping the variable air volume terminal unit serving the zone with the highest load fully open.

9.6.4 Unoccupied Ventilation (Night Purge)

Implementing this control strategy during the unoccupied hours (mainly during night hours) provides provision of a total building purge during unoccupied hours that not only removes large quantities of stalled contaminated air from the building in order to provide a higher indoor air quality, but also can help to provide some free cooling during these hours that would help to bring the energy consumption of the system during the following occupied hours.

9.6.5 Chilled Water Temperature Reset

In order to implement this control strategy, during the part load periods of the chiller operation the direct digital control system increases the cooling coil entering chilled water temperature incrementally in order to reduce the compressor work and as a result reduces the consumed energy by the system.

Reference

ASHRAE, Montgomery R, McDowall R (2011) Fundamentals of HVAC control systems—IP edition. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA

Part V
Energy Modeling, Sustainability Scoring Systems and Renewable Energy

Chapter 10
Energy Modeling

10.1 Basics of Load Calculations and Energy Modeling

The American Institute of Architects (AIA) in its publication (AIA 2012) recognizes four types of energy-performance modeling methods. These methods are Design Performance Modeling (DPM), Building Operations Modeling (BOM), Project Resource Modeling (PRM), and Building Energy Modeling (BEM).

Design Performance Modeling is a very introductory, simple, and fast energy consumption enhancement evaluation of the building in the early stages of the design. In this method designers attempt to roughly evaluate the possible effectiveness of energy consumption enhancement factors such as day-lighting and natural ventilation on the energy efficiency of their specific building.

Building Operation Modeling by definition requires to be performed after a few years of completion of the building. The advantage of this approach is that it is done based on the actual utility bills and weather data at the building location. This allows designer and the owner of the building to compare the real building energy consumption against the design model energy consumption. Such actual results can help to study, recognize, and target the causes of any possible deficiencies in the building and its systems and therefore creates an opportunity to improve the building performance to and even above the level which its original design was intended to be.

Project Resource Modeling is an extensive form of modeling that not only includes studying of the building consumed energy, but also is included of evaluating other factors such as material selection, site resources, resources that are brought to the site, and waste material use.

Finally Building Energy Modeling is the common tool for predicting the building energy consumption during the design phase. This model is regularly used in different stages of the design, and therefore requires more attention. Due to its importance, in the remaining of this chapter I will discuss BEM in more detail.

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Different commercial energy modeling software such as Trane Trace 700 and e-Quest are designed to assist the energy modeler to perform energy analysis for the buildings. A large number of building energy modeling and load calculations software are available in the market, each with its own weaknesses and strengths. For an extensive list of these software and their specifications refer to the department of energy web site. http://apps1.eere.energy.gov/buildings/tools_directory/alpha_list.cfm.

Let's continue with a brief discussion on how software such as Trane Trace 700 or e-Quest works. Trane Trace 700 is a load calculation and energy modeling software that is very popular among the HVAC professional community not only due to its ease of use and available comprehensive help documents, but also because Trane is one of the main equipment and controls manufacturers in the world as well. Trane Trace 700 help document not only assists the users to perform the desired building load calculations and energy modeling, but also provides a very thorough and informative guidance for describing the systems and advance controls. It also has the capability of customizing libraries and templates for different scheduling models.

Subsequently e-Quest is an energy modeling specific software with visual presentation capability of the modeled buildings. When a modeler uses e-Quest for modeling a multistory building, the software provides the capability to divide the whole building into only three sections. With e-Quest the modeler can model the lowest level and top level of the building separately and model the rest of the middle floors as one section. This approach is proven to be a very good estimate of how a multistory building consumes energy. Software is free and available for down load from the internet.

The main target of any energy modeling software is to provide predictions of the yearly energy consumption (cost) of the buildings. These predictions are made based on the calculated consumed quantity and cost of different utilized energy resources which are responsible for delivering cooling or heating (or other energy consumers in the building) to the building throughout the year. This process in general is similar to process of using load calculation software to select proper cooling and heating systems based on the calculated required cooling and heating loads in the building. The difference here is that in load calculation process the designer's target is solely calculating the building maximum required cooling and heating when it faces the most extreme conditions. Based on these results the designer will select the proper equipment sizes (capacity) that would be installed in the building. Such selection helps the system to be capable to offset the cooling or heating loads even when the worst conditions both in the outdoor environment and internal conditions happen simultaneously. On the other hand in energy modeling process the focus of the designer is not the worst instant condition, but it is the complete hourly load profiles and therefore the energy consumption (cost) throughout the whole year.

In order to perform energy analysis, multiple levels of information and data have to be entered to the software as the simulation inputs.

Even though the configuration and structure of the input information to these software may be somehow different from each other, but the underlying idea and basic information that are required to be fed to the different software is basically similar. Since almost all of software can generate some sort of output based on any type of input, it is important that only people who have sufficient degree of knowledge about the building, its systems and the logic of the software perform the energy modeling. Otherwise the reported results might be completely unreal and even useless.

Some software are designed only to be used for load calculations such as HCCV, and some are designed to be only used for energy modeling such as e-Quest. Some specific software such as Trane Trace 700 can be used for both purposes of load calculations and energy modeling. In the following paragraphs, I will describe the common required structure of any typical software that can be used for both goals of load calculations and energy modeling.

All these software generally have designated input spaces available for including the name and other general information about the project with some useful descriptions. These places can be used to describe the name and address of the project, name and address of the engineering firm that performs the load calculations or energy modeling, and any other general information that can be used for better identification of the project.

The next group of input information which should be entered to the software is usually the geographical location and the associated weather data for the specific project location. Most of the software is designed with a relatively large bank of weather data for many specific locations already built in it. In some cases simple tools for generating or entering the weather data for some specific locations that are not part of the general data storage of the software have been provided. Designer can either generate or simply import the proper weather data to the software where it is applicable. This weather data later will be used to calculate the cooling and heating capacity for the system to offset the effects of the outdoor environment on the inside of the building.

The next step usually is generating models for describing the different occupant densities, types of occupant functions (in order to create people sensible and latent loads), different lighting densities, and appliance densities. This type information helps the software to calculate what in general is called the internal load for each space within the building envelope. For example the inputs for a typical office building can be in the following format: (type of function: office area; occupant density: 70 square foot per person; people sensible load: 250 Btu per hour; people latent load: 200 Btu per hour; type of lighting: recessed fluorescent with a heat gain of 1.1 W per square foot; and type and density of appliances: 10 computers at 120 W each). Software always provides provisions for specifying the daily schedules for how each of these internal loads must be mapped in the calculations. For example the designer can specify the occupancy of the space in the following manner. From midnight to 7:00 A.M. 0 %, from 7:00 A.M. to 5:00 P.M. 100 %, and from 5:00 P.M. to Midnight 30 % of designated occupant density shall be considered for the people generated load in the calculations.

The next step generally is to set up the required outdoor airflow, thermostat, humidistat, and CO_2 level settings for each specific space. Relevant standards such as

ASHRAE Standard (ASHRAE 2013a) are generally being used to allocate proper minimum outdoor air required for each space. Other provisions such as expected infiltrated air, assigned exhaust air or other airflow settings along with the desired temperature, humidity and CO_2 level are being added to the calculations in this place.

The next step is to specify the characteristics of the construction material. Those characteristics are such as type, typical size and heating characteristics of different partitions, walls, roofs, slabs, skylights, windows, and doors. The heating characteristics of windows and skylights (glazing) are usually represented in form of U-values and shading coefficient, while the other construction materials are mainly specified only by their U-values, which is indicator of resistance of the construction material against heat transfer.

After these basic primary inputs, designer shall input a detail description of each specific space in the building. Depending on the size of the building, this step could be the most time consuming procedure, since all the different spaces of the building, their associated construction element maps, and designation of the internal loads shall be specified and added to the calculations at this time.

By the end of this step a relatively accurate physical model of the building and its different spaces have been built into the calculations and the next step logically is to define the type and characteristics of the HVAC air systems and equipment which will be used to air condition the building. This can include provisions such as defining system types (e.g., fan-powered terminal unit with reheat, chilled beams, fan coils); defining spaces with dedicated and/or supplemental cooling/heating (e.g., fan-coils, split systems, unit heaters); ventilation airflow rates; dedicated outdoor air system (DOAS) vs. mixed-air unit; building pressurization; ventilation schedule; infiltration; design vs. minimum air change rates; supply air schedule; exhaust air schedule; minimum terminal unit airflows; exhaust requirements; supply fan type, CFM, total static pressure, brake horsepower; return fan type, CFM, total static pressure, brake horsepower; motor efficiencies; return air path (plenum, ducted, room); supply air temperature heating, cooling; energy recovery, type, effectiveness; auxiliary HVAC, type (e.g., under floor radiant heating); humidification, type; system-specific requirements (e.g., chilled beam capacity).

The designer then shall define the cooling and heating plant equipment and configurations such as district plant; chiller or boiler type, number; pumping arrangement, type(s), full load energy rate, equipment curve; design chilled and hot water delta-T; chilled and hot water temperature reset, schedule; pump pressure optimization; waterside economizer, schedule; heat recovery, parameters; cooling towers; etc. Each air handling systems then should be assigned to the appropriate cooling and heating plants. Minimum efficiency of the different equipment, equipment schedules, and desirable applicable controls such as thermostat set-point(s), drift, schedules; humidistat set-point(s), drift, schedules; CO_2 sensors, set-point; airside economizer, type; demand control ventilation; supply air temperature reset; fan static pressure reset; pump head pressure reset; fan cycling; schedule (none, occupancy-based, load-based); night purge; morning warm-up; and optimum start, stop schedule shall be added to the calculation software at this time as well.

In addition, energy consumption rate of the different equipment and applicable utility rates and other necessary economic data such as utility rate schedule(s); elevator input power, schedule; domestic hot water system configuration, efficiency, capacity, schedule, hot water use reduction; site lighting power, and schedule shall also be added to the calculations at this time. When the target is energy modeling an alternative model similar to the design model shall be generated as well. The representative factors in this alternative shall be selected to matches the minimum requirements defined by ASHRAE standard (ASHRAE 2013b).

To summarize these steps, an energy modeling process uses the data delivered to the software regarding some important factors and generates the estimated building energy consumption and costs over a specific time period (usually one full year). Most important factors as it has been described earlier here are weather data, building orientation and geometry, building envelope, occupancy, lighting, miscellaneous equipment, HVAC systems. Other important factors that are required to be noted are service hot water, on-site power generation, operational schedules, and utility rate structures.

The final step is to run the simulation program and let the software to calculate the maximum required cooling and heating (in case of load calculations), and to depict a comparison of energy consumption (cost) between the design model and the alternative model which usually is called base building (in case of energy modeling).

At the end of this chapter, it should be reemphasized that building designers actually through an energy modeling exercise attempt to estimate the quantity of the consumed energy and its associated cost. Regardless of how good the designer is and how well the energy modeling software is developed, there are always conditions that would cause deviation of the results of the simulation from how much energy is really going to be consumed (or cost) when the actual building is finally built and is under operation. A few samples of these conditions can be named as variation in occupancy, variations in controls, variation in maintenance, change in energy rates and the most important variation in weather conditions. Therefore it should be clearly understood that the result of the energy modeling is not expected to show the exact energy consumption level or cost of the real building when it is built, but it is only a measure for differentiation between the design building and a baseline (imaginary) building both performed under similar conditions, with similar software, but different systems.

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Chapter 11
Sustainability and Energy Conservation Scoring Systems

Human technical advancements during the industrial age have led to many inventions in different fields. In building industry inventions such as utilization of refrigerants like chlorofluorocarbon (CFC), and hydro-chlorofluorocarbon (HCFC) in manufacturing buildings air conditioning systems, using Halon (a compound made of bromide, fluorine and carbon) in building fire distinguishing systems, and using carbon-based fuels in the forms of burning wood, coal, oil, natural gas, or any other sub-product of these materials for electricity generation in power plants have changed the face of the industry drastically. Even though these are some of the major contributors to the advancement of the buildings and building technologies during these years, unfortunately the advancement of the building technologies is not these items sole effect. These innovations had also been proven to create some notable negative consequences for both people and the environment.

Halons, CFCs and similar refrigerant agents usually remain very stable while they are near the ground. They have a good potential to stay on ground level after breaking out of their systems, e.g. refrigerant leak from the refrigerant system, and they will remain there until the climate activities such as wind push them to higher elevations, while they are still stable. They stay stable until they reach the ozone layer that is approximately 10–25 miles above the earth surface. When these refrigerants reach the ozone (O_3) layer the condition will change. Due to the higher intensity of the ultraviolet radiation in this layer, these compounds break apart and release agents of chlorine and bromide. Chlorine and bromide have great potential for rapidly interact with O_3. These interactions force one atom of O to separate from the O_3 molecule, and due to the rapid rate of interaction the amount of O_3 molecules in ozone layer intensively decrease. This event when continuously happens will deplete the ozone layer which reduces the earth protective shield against sun ultraviolet radiation. As ozone layer depletes larger quantity of sun radiation can reach the earth. This higher degree level of radiation can cause different complications such as people skin cancer. It also can generate additional warming effect on the earth which as a consequence will contribute to global warming phenomenon.

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As the sun radiation hits the earth and objects and people on it, some of this radiation absorbs and increases the temperature of earth and objects on its surface. This effect causes the earth and objects located on its surface generate infrared thermal radiation and send it back up towards the atmosphere.

Ozone, water vapor, nitrous oxide, methane and many other gases, which exist in the earth atmosphere and are known as greenhouse gases, have the capability of absorbing the deflected infrared thermal radiation of the earth and other object on its surface. One of the major greenhouse gases is CO_2 that is after-production of carbon-based fuels as source of energy generation. CFCs, HCFCs, HFCs, and volatile organic compounds (VOCs) act as greenhouse gases as well. The specific attribute of the greenhouse gases which is their capability to reflect the absorbed thermal radiation in all directions, causes some of the heat that was on its way to leave the earth atmosphere reflects back towards the earth. When this function repeatedly is done, creates additional heat near ground that causes the earth temperature to rise. This effect is known as global warming, which is known to be responsible for climate change and some extreme tsunamis or earth poles ice melting in the recent years. Top human generated greenhouse gases that contribute to global warming are CO_2, CH_4 and N_2O. Even though these greenhouse gases which also naturally occur in the atmosphere but based on a report by Intergovernmental Panel on Climate Change (IPCC) and National Oceanic & Atmospheric Administration (NOAA) the atmospheric concentration of these greenhouse gasses in the past 250 years (industrial era) have increased by 39 %, 158 %, and 18 %, respectively.

Ozone depletion and global warming are the most critical one–two punches that the industrial age and as a major component of it, the building construction industry has hit the people, the earth and its environment with. For more information on this subject see (http://www.epa.gov/).

As extreme usage of refrigerants in chillers and other machines and consequently its leakage has endangered the atmosphere by depleting the ozone layer, and as uncontrolled consumption of energy sources has endangered the easy access to energy resources, different protocols and committees have diverted their attention to higher efficiency systems with lower damage to the environment and use of sustainable energy sources. Designers that their main goal was to design for the occupant's comfort, faced other more critical criteria to comply with, such as sustainability and design to the highest efficiency levels with no damaging effect to the environment.

One of the most internationally influential organizations in this field is American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) which was founded in 1894 at a meeting of engineers in New York City. ASHRAE publishes a monthly journal, a set of four handbooks every year (once in 4 years each), and performs multiple meetings throughout the year. Its four handbooks of Refrigeration (ASHRAE 2014), Fundamentals (ASHRAE 2013b), HVAC Systems and Equipment (ASHRAE 2012), and HVAC Applications (ASHRAE 2011b) that are revised and republished every 4 years in order are one of the most valuable resources for designers and researchers in HVAC field. ASHRAE also has published numerous standards regarding most aspects of design, control, and commissioning of HVAC systems. The instructions of ASHRAE Standard 90.1 (ASHRAE 2013a), sometimes also referred to as energy code, are basically what all the designers shall follow to be able to achieve building energy efficiency compliance evaluation throughout the USA (Khazaii 2012).

Leadership in Energy and Environmental Design (LEED) is an internationally recognized green building certification system, which as a third party verifies whether a building is designed and built using proper green and sustainable strategies. This scoring system defines provisions for improvement of most aspects of the whole building such as energy saving and CO_2 emission. LEED organization was established in 1993. From 1994 to 2014, LEED grew from one standard for new construction to a comprehensive system of multiple guidelines targeting improvement of the site and building development and construction process.

Another sustainability system, the Green Building Initiative (GBI), established in 2005, and its target was to ensure that all buildings, regardless of size, type or budget, are built and managed in an environmentally-friendly manner.

In 2009 and in order to create a labeling system for the different buildings ASHRAE members started working on a labeling program that was fully lunched in 2011. The target of this program is to provide the design and construction community with information on the potential and actual (measured) energy use of buildings. The ASHRAE Advanced Building Energy Labeling (ABEL) program is based on the Building Energy Quotient (bEQ) label, together with a supporting certificate. The label is pertinent for existing buildings, using the As Operated (Operational) Rating, and for new buildings using the As Designed (Asset) Rating. The ratings are planned to support regulatory energy use requirements. bEQ Scales the buildings from site and source energy, on-site renewable sources and emission stand points and provides a grade between smaller or equal to “0” and larger than “145.” There are seven layers of scaling with A+ (smaller or equal zero) as the best and F (larger than 145) as the worse cases.

In 2009 ASHRAE, LEED, and two other significant institutes, American National Standard Institute (ANSI) and Illuminating Engineering Society (IES), aligned their forces together and published a comprehensive standard named “Standard 189.9-2009—Standard for the Design of High-Performance Green Buildings-Except Low-Rise Residential Buildings.” The purpose of this standard that revised and republished in 2011 (ASHRAE 2011a) is to depict the minimum requirements for the site selection, design, construction, and plan for operation of high-performance green buildings with a responsible attitude towards environmental and resources. As it has been targeted and claimed, it also designed to support the goal of development that meets the needs of the present without compromising the ability of the future generations to meet their own needs.

Prior to these efforts in USA, the European Committee for Standardization (CEN) which is a nonprofit organization and its mission is to advance the European economy, improve the welfare of the European citizens and protect the environment by providing proper standards and specifications, was established in 1961. One of the goals of CEN is to provide a unified standard for energy conscious design throughout Europe (Khazaii 2012).

Meanwhile worldwide movements for standardization of the energy conscious design have been working towards sustainable and energy efficient buildings in Canada, the UK, Japan, Qatar, etc.

All these efforts show that building design and operation in general and HVAC system design and operation as one of the most important energy consumers in the buildings have been subjected to more focused energy efficient design more than any other time before. For example, out of a total hundred points available for LEED 2009 certification for new constructions, in Energy and Environment (EA) section, nineteen points are designated for optimizing energy performance and three points are designated for measuring and verifying the system different components, and a few more credits in Indoor Air Quality (IEQ) section are designated for controlling and monitoring preferable condition for indoor air quality. These points are directly related to the HVAC system efficiency and operation e.g. outdoor air delivery monitoring and thermal comfort controllability (Khazaii 2012).

As it shows the design engineers now are expected to select more efficient systems for designing buildings and are responsible for wisely consuming energy sources without allowing their designs to leave adverse effects on environment, and in order to do so they have to satisfy the requirements and regulations developed by the different sustainability scoring systems.

In the following paragraphs I briefly introduce some of the important energy scoring systems that are more common and are frequently used throughout the world as the sustainability evaluating and scoring tools.

11.1 BREEAM

Building Research Establishment Environmental Assessment Method (BREEAM) was the first standard in United Kingdom in last decade of past century that was developed to advocate sustainable design and has been used to calculate and describe the performance of different buildings since then.

As it is described in BREEAM official web site "http://www.breeam.org/," BREEAM UK is consisted of BREEAM New Construction, BREEAM Communities, BREEAM In-Use, Eco-Homes, BREEAM Refurbishment, and Code for Sustainable Homes. BREEAM Europe Commercial can be used to assess office, retail, and industrial buildings in any European country, BREEAM International Bespoke can be used for assessment of a single building anywhere in the world, and BREEAM In-Use can be used for helping managing existing buildings anywhere in the world. If a building cannot be categorized under any of the specified standard schemes described in BREEAM, then "BREEAM other Buildings" standard can be utilized to evaluate that building. The UK, Germany, the Netherlands, Norway, Sweden, and Spain are the major countries that use tailored versions of BREEAM systems. Other countries can use BREEAM International scheme which is a more general standard with less customization.

Different levels of classification presented by BREEAM are (1) "pass" for qualifying for at least thirty percent of all possible credits, (2) "good" for qualifying for at least 45 % of all possible credits, (3) "very good" for qualifying for at least 55 % of all possible credits, (4) "excellent" for qualifying for at least 70 % of all possible credits, and (5) "outstanding" for qualifying for at least 85 % of all possible credits.

BREEEAM environmental subjects of interest are included of land use and ecology, water, energy, material health and wellbeing, transport, waste, pollution, management, and innovation. Among these subjects energy, health and wellbeing and management have the highest percentage weight.

A report "A comparison of BREEAM and LEED environmental Assessment methods" prepared for the University of East Anglia in 2011 stated that BREEAM as of year 2009 was the most adopted environmental assessment method in the world with more than 200,000 certified projects, following by LEED with more than 24,000 certified project.

11.2 HQE®

High Environmental Quality (HQE®) was the second system after BREEAM that was developed in 1996 to address the effects of the buildings on environment in France. HQE® standard approaches both organizational (relation between different involved parties) and operational aspects of the building. As it is indicated in the HQE® official web site "http://assohqe.org/hqe/," the action of this association is focused on structures and operational planning for individual housing area, business parks, new building renovation, rehabilitation and operation. To comply with HQE®, a building shall meet 14 targets in 4 different categories. These are "Eco-construction" such as relation between buildings and their immediate environment, "Eco-management" such as management of energy and water, "Comfort" such as acoustic and visual comfort and "Health" such as sanitary air and water quality.

HQE® reviews the building from the above mentioned 14 points of view and certifies the building on a 3 levels performance category base called "Basic", "Good" and "Very good."

Recently has been an ongoing process to bring HQE® and BREEAM assessment methods together in order to make a unique certification scheme in France consistent and comparable with the other BREEAM certifications in Europe.

11.3 LEED

Leadership in Energy and Environmental Design (LEED) was originated in the USA by the US Green Building Council (USGBC) in 2000 and has been evolving since then. Since its inception the LEED target has been to introduce and implement goals of a sustainable and green design, built, control, and monitoring for buildings.

As indicated on the LEED website "http://www.usgbc.org," LEED has grown from a single document to multiple documents proper for different types of applications.

These applications currently are LEED for New Construction (and major renovations), for Existing Buildings (operations and maintenance), for Core and Shell development, for Schools, for Retail, for Healthcare, for Commercial Interiors, for Neighborhood Development and for Homes.

In general and similar to other sustainability scoring systems all the different LEED standards are targeting subjects such as site sustainability, water use management, energy and atmosphere, material election, and indoor air quality.

In LEED 2009 for new construction and major renovations achieving a maximum total of 110 points is possible, which a minimum of 40 points is required for certification. Also a minimum of 50, 60, and 80 points are respectively required for a silver, gold and platinum level of certification.

In site sustainability section means of improving the building by controlling effects of functions such as construction activity pollution, public transportation, storm water quantity and quality control, heat island effect and light pollution reduction are discussed. Advocating use of low emitting and fuel-efficient vehicle, lowering the number of parking space capacity to force public transition, and use of maximum open spaces are discussed here as well. In this section 1 prerequisite and a total of 26 credit points are possible to be achieved.

Subjects of discussions in water efficiency section are means of reduction of water use, innovative wastewater technologies, and process water use reduction. In this section one prerequisite and a total of ten credit points are available for achieving.

In energy and atmosphere section attention is focused on commissioning of the building, minimum energy performance, refrigerant management, on-site renewable energy and measurement and verification of the consumed energy. In this section 3 prerequisites and a total of 35 credit points are available for achieving.

In material selection section directions for using proper material for construction is discussed. Storage and collection of recyclables, construction waste management, recycled contents, regional materials, rapidly renewable materials and certified wood are subjects of discussion in this section. In this section 1 prerequisite and a total of 14 credit points are available for achieving.

Finally indoor environment quality section is concerned with subjects such as minimum indoor air quality, construction indoor air quality management during construction and before occupancy, low emitting materials, occupant comfort design, controllability and verification, lighting controllability, and daylight. In this section 2 prerequisites and a total of 15 credit points are available for achieving.

There are also two additional sections of innovation and design process and regional priority for a total of ten extra bonus points.

11.4 CASBEE

Comprehensive Assessment System for Built Environment Efficiency (CASBEE) is a measure to promote sustainability that is developed for the state of Japan in 2001. As it is indicated on the CASBEE website, "http://www.ibec.or.jp/CASBEE/English/index.htm," the main concepts that CASBEE has been developed around is advocating construction of superior buildings while maintaining simplicity and applicability of the buildings in Japan and Asia.

CASBEE is composed of four assessment tools, CASBEE for predesign, for new construction, for existing buildings, and for renovation which along with the other tools for special purposes are called CASBEE Family.

CASBEE for predesign (underdevelopment) assists professionals who are involved in planning stage of building to understand issues such as environment impacts of the project. It also helps them to evaluate the environmental performance of the project at the predesign stage.

CASBEE for new construction helps architects and engineers to improve the building energy efficiency by implementing the recommended strategies in this tool during its design process.

CASBEE for renovation introduces the building managers to methods of providing building operation monitoring and commissioning for the existing buildings.

The other CASBEE tools which are designed for specific purposes are CASBEE for detached houses, for temporary construction, brief versions, local government versions, for heat island effect, for urban development, and for cities.

CASBEE system has been developed based on assessment of two distinct categories of (1) positive impact of the building system inside the boundary of the building site, and (2) negative effects of the building system outside the building site boundary. To evaluate the positive impacts inside the building system boundary, CASBEE focuses on quality of the building performance, quality of indoor environment, quality of service and quality of the outdoor environment at the building site. On the other hand to evaluate the negative effects of the building system outside of the building system boundary, CASBEE assesses the environmental load, energy consumption, use of material and resources and outdoor environment outside the building system boundary.

CASBEE system uses these two overall assessments to define the indicator of Building Environmental Efficiency (BEE) based on the ratio of the assessment of total “Q” to assessment of total “L,” or ratio of the quality of the building to the environmental effects of the building.

CASBEE ranks the buildings based on one of the following categories of excellent (S), very good (A), good (B+), rather poor (B−), and poor (C).

The indicator BEE for a poor building is anything below 0.5, for a rather poor building is anything between 0.5 and 1, for a good building is anything between 1 and 1.5, for a very good building is anything between 1.5 and 3, and for an excellent building anything above 3.

11.5 Other Sustainability Scoring Tools

As it was briefly mentioned earlier in this book in different countries some other sustainability scoring tools have been developed which are custom made for the countries of interest. Some of these systems and the countries that using these tools are Green Globe for Canada, Green Star for Australia, HK-Beam for Hong Kong, QSAS for Qatar, etc.

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Chapter 12
Renewable Energy and Sum-Zero Energy Buildings

In the past few decades the diminishing resources and consequently the higher prices of fossil-based energy, and also increasing public awareness and understanding of the massive damages that utilizing the common fossil-based energy resources such as coal and gas impose to the environment have made the engineers to investigate new and clean resources of energy. These new and clean resources mainly are known as renewable energy. The renewable energy (sustainable energy) is commonly defined as resources of energy that can be reused time after time without short changing the future generations from reliable resource of energy and would not create harmful residuals that can threat the people health and the environment cleanness.

At the same time architects and engineers attentions have moved towards designing such buildings that from the energy consumption stance are more efficient, and since building industry counts for a very large portion of energy consumption in the USA and also the rest of the world, attention has been paid towards designing buildings which are even energy self-sufficient as well. These buildings when are responsible for producing hundred percent of their daily (yearly) energy usage, would be called sum-zero energy buildings.

In the following section I will briefly review some of the different available types of renewable energy and also some techniques for designing a so called sum-zero energy building. One of the most valuable resources of information about renewable energy types can be found in the US Department of Energy website "http://energy.gov/", that I referred to that when developing the following section.

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12.1 Renewable Energy Types

12.1.1 Geothermal Energy

Geothermal energy generation which is using up the energy that is generated and stored in earth is not a new technical advancement due to the fact that it has been used for power generation since early twentieth century. But recently and not only due to importance of energy conservation but also because of high electricity producing potential of geothermal systems its utilization has been reconsidered by the engineers.

Different technologies of utilization of the geothermal energy can be divided into four major categories of conventional hydrothermal systems, low-temperature systems, enhanced geothermal systems, and direct-use systems.

In general conventional hydrothermal, low-temperature, and enhanced geothermal systems are all used to generate electricity, while the direct-use systems that ground source heat pump systems are a major member of this category are used for space heating and cooling systems, hot water production, industrial processes, agricultural processes, etc. Based on 2008 geothermal technology market report (July 2009) the utilization of geothermal direct use energy from year 1990 to 2007 has grown from 0.0048 to 0.0094 quadrillion Btu (almost twice as much). Also based on 2010 geothermal energy international market update, electricity generation from geothermal resources in the USA has risen from 2,678 MW in 2007 to 3,086 MW in 2010.

To be able to generate electricity from a conventional hydrothermal system in addition to earth heat two other resources of hot fluid (steam or hot water) in an underground reservoir and permeability of the earth structure shall be naturally available in one place. A production (supply) well will be used as a path for bringing the hot fluid to the power plant and an injection (return) well will be used for returning the low-heat-low-energy fluid back to the reservoir. High energy fluid which has moved through the production well will be delivered to the power plant turbines. Power plant turbines use this energy to run the generators that consequently generate electricity. Commonly there are three different types (dry steam, flash steam, and binary cycle) of interactions between the turbine and the working fluid. In a dry steam power plant, the steam out of the production well will be directly introduced to the turbine, while in flash steam power plant steam enters a flashing container with much lower pressure to be converted to flash steam before entering the turbine. In a binary cycle power plant fluid from the production well introduces to a heat exchanger in which the ground heat will be transferred to another closed circuit fluid with a much lower boiling point. This fluid then is used to run the turbines (Figs. 12.1, 12.2, and 12.3)

The difference between a conventional hydrothermal system and an enhanced geothermal system is that in the latter the main three elements of reservoir with the fluid, earth heat and permeability are not available naturally in one place, and usually additional effort such as increasing the permeability of the earth structure is needed to generate the proper environment for utilizing this system.

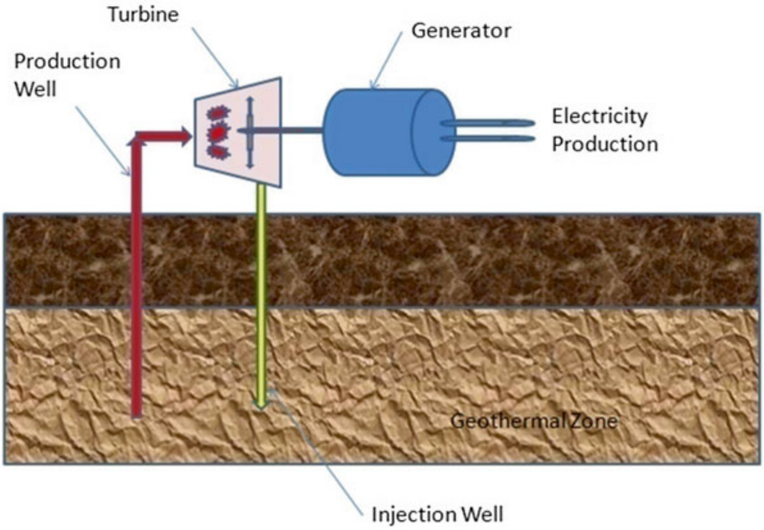

Fig. 12.1 Dry steam geothermal system

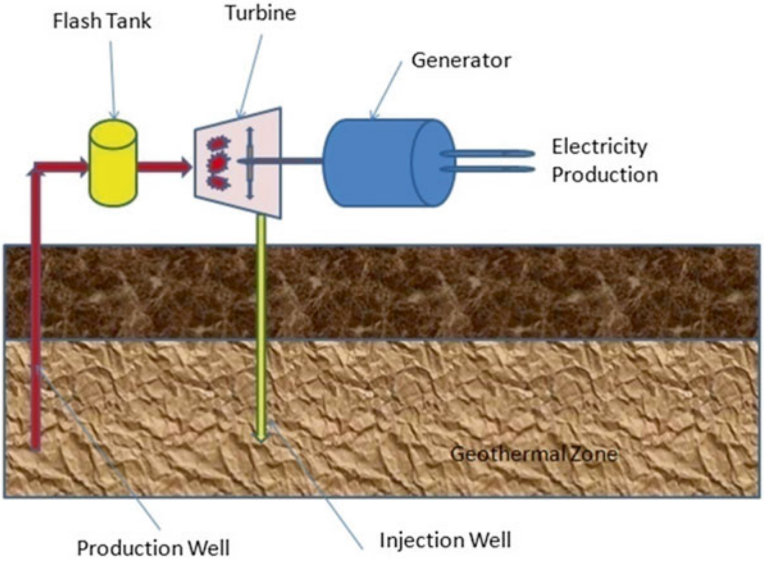

Fig. 12.2 Flash steam geothermal system

Traditionally a low temperature geothermal system is known as a system which the temperature of geothermal fluid is below 300 °F. Other than binary cycle systems that are being utilized for electricity generation, generally the other low-temperature geothermal systems are being used as direct systems which have other applications than electricity generation.

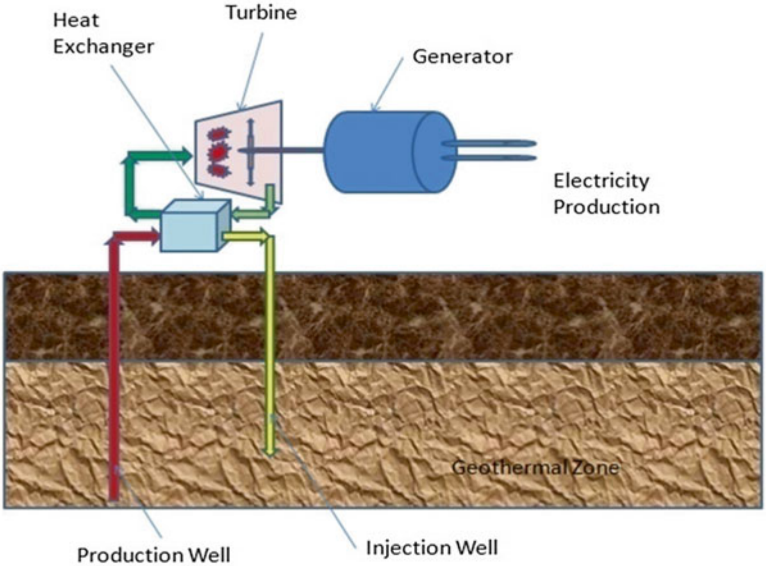

Fig. 12.3 Binary cycle geothermal system

Ground source heat pumps which are categorized and basically cover a majority portion of the direct systems, use the relatively constant temperature of the earth below its immediate surface in order to generate heating or cooling for residential and commercial buildings. For a more detail description of these units refer to types of HVAC systems and system selection chapter in this book.

12.2 Solar Power Technologies

A research performed in University of Michigan "http://css.snre.umich.edu/css_doc/CSS07-08.pdf" shows the world electrical demand is less than 0.2 % of the total Sun radiation (1.05×10^5 terawatts (TW)) that reaches to the earth surface. Therefore finding ways to convert this radiation into suitable electricity can be very valuable. Two of these methods are utilization of what we call photovoltaic (PV) solar cells and concentrating solar power systems. Next two sections are dedicated to discuss these two systems in brief.

12.2.1 Photovoltaic (PV) Technology

A photovoltaic (PV) solar panel is a solar panel capable of creating electrical power from sunlight. Photovoltaic cells generally are made of multiple layers of semiconductors such as silicon. These panels when are exposed to the Sun light generate a direct electrical charge (DC). This direct charge then, through utilization of an inverter can be converted to an alternative charge (AC) which would be suitable for building electricity needs.

Photovoltaic cells main design structures are homo-junction devices, hetero-junction devices, p-i-n and n-i-p devices and multi-junction devices. Photovoltaic cells have also been categorized under two main types of Crystalline Silicone (wafer based) and Thin Film. Subcategories of Crystalline Silicone type are Poly-Crystalline and Mono-Crystalline, while subcategories of the Thin Film type are Amorphous-Si (a-Si), Tandem (a-Si/microcrystalline), CIGS (Copper Indium Gallium Selenite), and CdTe (Cadmium Telluride).

Crystalline silicon is a homo-junction device that is made of one single material of crystalline silicon in which one side has positive and the other side has negative charges. When light absorbs in this material create free electrons. The freed electrons move from one side to other and therefore generate an electrical current. In crystalline silicone technology single slices of silicone undergoes numerous manufacturing processes and then array of these single slices are put together in order to create a crystalline silicone panel. These panels then will be located on the roof or other building surfaces facing the sunlight to use its energy and generate electricity.

Generally crystalline cells are made of pure silicon of one hundred and fifty to two hundred (150–200) microns thick, while the thin films are made by depositing semiconductor layers onto glass or other specific material (mainly stainless steel). Thin film layers are approximately three tenth to two (0.3–2) micrometer thick.

In thin-film technology which uses a hetero-junction device the junction is formed from different semiconductors, such as copper indium gallium selenite (CIGS). Copper Indium Gallium Selenite is a direct bandgap semiconductor material that can absorb the sun energy with very high efficiency level. Due to possibility of using different semiconductor as the positive and negative ends, devices that use this technology provide higher efficiency than other devices using homo-junction technology.

As it was said earlier other thin-film technologies exist as well. An amorphous silicon (a-Si) thin-film technology uses a p-i-n (positive a-Si, intrinsic silicon, and negative a-Si) structure, while a cadmium telluride (CdTe) uses a n-i-p (negative zinc telluride (ZnTe), intrinsic CdTe, and positive cadmium sulfide (CdS)) structure. Each of these devices are made of three layers of semiconductors that each have one of the positive, negative and neutral charges, with the neural layer located in the middle of the other two layers.

Another type of thin-film photovoltaic cells is Multi-junction device. These devices also called cascade or tandem and are made of multiple layers of semiconductor junctions, which by capturing different levels of energy of light in multiple layers provide higher efficiency devices. In this structure multiple stacks of single junction cells are installed on top of each other. The order of installation from top to bottom is from higher to lower band-gap, in which the upper level captures the highest energy light photons and the bottom level captures the lowest energy light photons.

As per National Energy Foundation website which is based in the UK, "http://www.nef.org.uk/renewableenergy/pv-basics.htm," the most efficient exposure for locating the PV panels is on the roofs facing an exposure between southeast and southwest. But the most important fact regarding these units is that even a minimal amount of shading can reduce the efficiency of the panels considerably. Common efficiency of these panels depending on the type of the used semiconductor and manufacturing technology usually is somewhere between 5 to 15 %.

High temperature on the surface of the PV panels can also cause the loss of efficiency of the PV panel. This efficiency loss can be calculated by multiplying a factor that is called temperature coefficient by the difference between the environment temperature and rated temperature of the PV panels. Depending on the type of the used technology the temperature coefficient can be anywhere between two tenth to five tenth percent per one degree of Celsius (0.2–0.5 %/°C).

On average for a properly installed panel assembly of 1 kW-peak (maximum output), an annual 750 kW h of output can be expected.

12.2.2 Concentrating Solar Power Systems

A Concentrating Solar Power (CSP) is an assembly in which sun light is concentrated to heat up a working fluid. This heated working fluid then will be utilized to run a turbine or an engine which starts a generator in order to generate electricity. Main utilized systems for this purpose are Linear Concentrator Systems, Design-Engine systems, and Power Tower systems. It is common for these systems to be designed with a supplemental thermal storage system in order to make up for the periods of time that Sun power is not available.

Two popular types of Linear Concentrator systems are Parabolic Trough and Linear Fresnel Reflector systems. In a parabolic trough system (Fig. 12.4), parabolic reflectors are installed in a general north–south direction. The control system swings these reflectors in such way to follow the movement of the Sun as much as possible.

These reflectors direct the maximum possible Sun energy towards a group of collector pipes which carry working fluid. These collector pipes are located in the focal point of the parabolic surfaces and their function is to heat up the working fluid inside them using the absorbed Sun energy. The contained heat inside the working fluid then via utilization of a heat exchanger will be transferred to a steam generating water cycle. Generated steam in this cycle then will be delivered to a turbine. Steam will run the turbine shaft which finally will be transferred to an electricity generator for generation of electricity.

In a linear Fresnel reflector system, similar procedure happens through flat long mirrors individually following the movement of the sun and heating up the working fluid inside of the collector pipes located at the focal point of the mirrors (Fig. 12.5).

A Dish-Engine system is a relatively small size electricity generator with an electricity generation target of mostly less than 25 kW. It is made of a parabolic dish

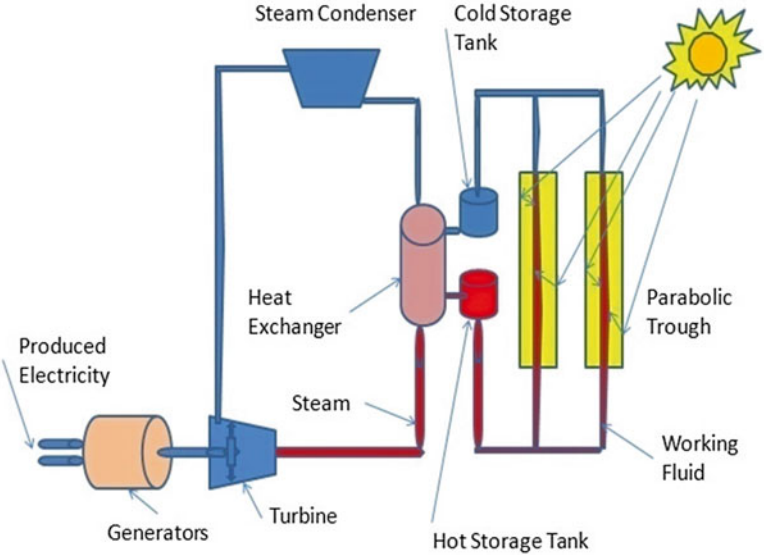

Fig. 12.4 Parabolic trough linear concentrator system with direct storage tanks

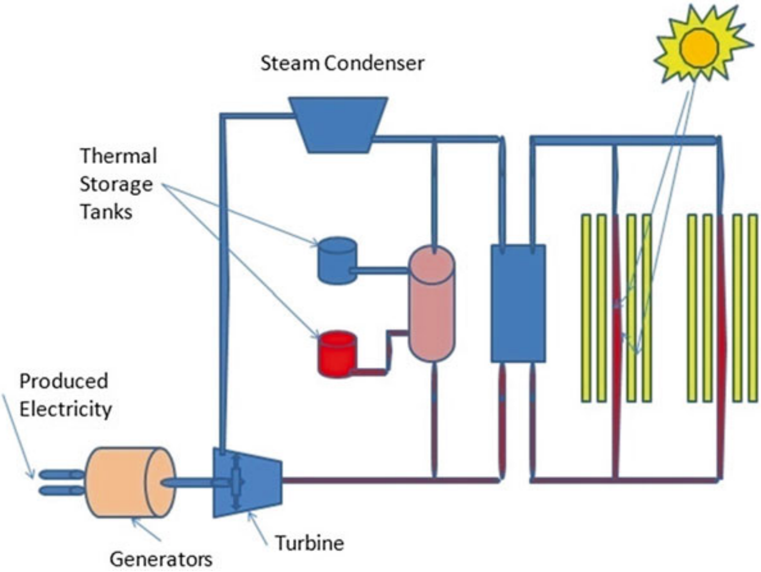

Fig. 12.5 Linear Fresnel reflector system, with indirect storage tanks

made of reflecting mirrors which will concentrate the Sun light on a power convertor section in the focal point of the dish. Energy transferred to this section usually will be used to heat up the working fluid which moves a reciprocating shaft system that then will be used to start and operate an electricity generator unit.

Power Towers are another type of concentrating solar power systems. In these systems a large number of flat mirrors track the Sun movement and focus its light towards a receiver which is installed on top of a tower. This system like the other systems in this category uses the Sun energy to warm up the working fluid in a receiver. The warmer fluid then will be used to run a turbine and then generates electricity by using the mechanical power output of the turbine as the input to an electricity generator.

As it was mentioned earlier, the main problem with concentrating solar power systems is it’s down time. Down time is the result of lack of sun radiation during the night and cloudy day times. To overcome this problem storage tanks have been designed and are used. Storage tanks hold the additional generated energy during the day times and utilize it during the down times. Three popular types of storage tanks are two-tank direct, two-tank indirect, and one tank thermo-cline systems.

A two-tank direct storage system is contained of two tanks with high and low temperatures which utilize the same fluid as heat exchanger and storage fluids. Hot fluid from thermal collectors arrives in high temperature tank and from there moves to a heat exchanger that generates steam for running the steam turbine, which provides the mechanical power required for a generator to generate electricity. Cold working fluid from the heat exchanger moves back to the low temperature tank and from there returns back to the collectors.

The main difference between two-tank direct and two-tank indirect storage systems are that in the latter system the heat exchange and storage fluids are two different fluids. This usually occurs when the heat exchange fluid is expensive, and it is not economical to fill both tanks with this fluid. As a result the system requires an additional heat exchanger that separates the heat exchange (collector) fluid from the storage fluid. In this configuration the collector fluid passes through two heat exchangers in parallel position. The steam heat exchanger transfers the collector fluid heat to steam generating fluid which as the result will generate electricity after being changed to steam and going through turbine and electricity generator. The utilized fluid in hot and cold storage tanks will be pumped into each other with two pumps in reverse direction and as it is defines by the need for direction of the fluid between two tanks. During the day time when hot collector fluid is available, storage tank fluid is pumped from cold tank to hot tank and absorbs heat from collector fluid inside the storage heat exchanger and stores this heat in hot tank. During the down time when sun is not available, hot fluid is pumped from hot tank to cold tank. The difference is that in this time collector fluid absorbs the heat to warm up and further get utilized in the steam heat exchanger for generating steam and electricity.

One tank thermo-cline system is contained of one tank with three levels of solid material with high, medium and low temperatures. High-temperature working fluid enters to high temperature media on top and leaves from the low temperature media in the bottom.

12.3 Wind Power

Wind can be generated as a result of uneven heated earth surfaces, locations pressure differences and earth rotation. Wind turbines can be utilized to receive the kinetic energy of the wind and transform it to clean renewable electricity by employing electricity generators. Generally wind turbines are either horizontal axis or vertical axis type, where the earlier type with two or three blades is the most popular one. Wind turbines are made of combination of turbine, gear set, generator, and controllers that are installed on top of a tall (around 100 ft above ground) tower. As wind moves through the aerodynamically designed blades of the turbine, generates two different pressure regions in front and back of the blades. This differential pressure causes the blades to rotate. Low rounds per minutes (rpm) rotation of the blades through the blades shaft and the gear set will be converted to a rotation with high rpm. This resultant fast rotation then will be delivered to a generator which as a result generates electricity.

The main difference between a horizontal and a vertical axis turbines is that the first one needs to be directed toward the wind, but the latter one does not need to be located towards the wind, but is much slower and requires much higher torque to operate. Due to considerable slow rotation of vertical axis turbines they are generally not suitable for electricity generation.

Smaller scale wind turbines can be used for residential buildings which mostly can produce only 0.3–10 kW. These wind turbines can be installed either on top of the roof, or somewhere on the building site that can catch the available wind at the site.

12.4 Biomass, Biofuel, and Bio-Power

12.4.1 Biomass

During the day plants and vegetables use Carbon Dioxide (CO_2) which is in the air along with water and of course sun energy through the photosynthesis process to create some sort of sugar inside them that helps them to grow. By-product of this function is generation of O_2 which is deposited back to the air, and will be inhaled by humans and animals and of course plants and vegetables during the night time. The respiration system of humans and animals and plant and vegetables over the night hours uses the inhaled O_2 and returns CO_2 to the air through their exhale function. When humans and animals consume plants and vegetables carbon moves from plants and vegetables to humans and animals bodies. That helps them to grow as well. Human and animal waste also adds carbon to this process of carbon exchange which is called carbon cycle.

Carbon existed in long time dead body of humans, animals, and plants and vegetables which is buried under the layers of earth, if is deep enough and if stays there for a long period of time (million years) will be changed to diamond, coal or other types of fossil fuels that can be burned, generate heat and energy, and release CO_2 to the air. On the other hand, biomass material is referred to live or recently dead plants, vegetables or plant related material that can be either directly or indirectly (e.g., biofuel) used to provide heat and energy. Dedicated energy crops, agricultural crops residues, aquatic crops, forestry residues, biomass processing residues, municipal wastes, and animal wastes are common different types of biomass resources.

Dedicated energy crops are those plants such as Bamboo that offer the advantage of being repeatedly regrown from the same roots in a relatively short time cycle. These crops therefore reach their full productivity level in a few (usually 2–3) years after being harvested and processed.

Another biomass type is agricultural crops residues that can further be subdivided into two smaller categories of field residues and process residues. The field residues are those left in the field after harvesting the crops such as leaves and stems. Process residues are what that have left after the crops are processed to final usable resources such as seeds and roots. The most important characteristics of residues of agricultural crops is that they are biomass materials that usually other than capability of being used as biomass resources have no other commercial application.

Two other main types of biomass resources are aquatic crops such as algae, and forestry residues such as dead trees. Biomass processing residues are biomass resources such as unused sawdust or branches of trees and municipal and animal waste biomass resources are post-consumer wastes and animal-processing waste respectively.

Different technologies can be utilized for breaking down biomass materials in order to release the stored sun energy in them. The most important of them are biofuel and bio-power.

12.4.2 Biofuels

Biofuels can be in either solid, gas, or liquid form. Ethanol and biodiesel are the most common biofuels. In the USA generated ethanol is either fermentation ethanol (bio-thermal) type (which is either corn base or cellulosic material base) and is used as an additive to petroleum-based fuels, or synthetic ethanol type which is produced from ethylene and it is mainly used for industrial applications. The most significant characteristic of ethanol are its capability to increase the octane of the fuel and decrease its air pollution effects.

Biodiesel (ethyl or methyl ester) is generated through combining organic oils with alcohol in presence of a catalyst. This product can be either used as pure biodiesel fuel or as an additive to regular diesel fuels with different percentages.

Another category of biofuels are known as Bio-Oils, which are produced through the process of fast and flash pyrolysis. The generated fuel through this process can be the source of energy for some boilers. In a fast and flash pyrolysis process solid fuel is heated up to about 500 °C for a very short period of time to generate bio-oil fuel.

12.4.3 *Bio-Power*

Bio-power is the generation of electricity or heat from biomass resources. Main technologies that are used for bio-power generation are direct combustion, co-firing, and anaerobic digestion.

In a direct combustion method, which is the most common technology, waste wood from agriculture and wood processing industries directly burns in a wood burning boiler to generate steam. This steam will be used to spin a turbine which spins a generator and therefore can generate electricity.

In a co-firing system, part of the petroleum based fuel is replaced by biomass, which in result can reduce the emission of petroleum based power plants significantly. In an anaerobic digestion technology, bacteria are used to decomposes the organic waste and produce methane which can be piped and used to produce electricity or heat.

12.5 Hydropower

Using water in order to provide power for running a machine or to generate electricity is known as hydropower. Hydropower plants can be generally categorized to impoundment, diversion, or pumped storage types.

In an impoundment system which is the most common type of hydropower plants, usually a dam is used to accumulate a river's water behind it. The stored power in this accumulated water would be utilized as the source of power to run a turbine. The spinning shaft of the turbine then generates the input power for an electricity generator, which finally and in exchange generates electricity.

In a diversion type facility, a small stream of the river's water is branched out from the main river body of water in a higher elevation. The diverted branch of the river's water will be directed to a turbine in the plant and makes the turbine to rotate. Similar to the previous method the spinning shaft of the turbine will be the initial power to a generator which in exchange will generate electricity. The diverted water in this process then will be redirected back to the main river in a lower elevation.

In a pumped storage facility, during the hours that the electricity demand is low, the water energy will be stored by pumping water from a lower reservoir to an upper reservoir. During the hours that the electricity demand is high, this water will be released to the lower reservoir to create electricity, by using a turbine and generator assembly, similar to the other discussed methods above.

12.6 Ocean Energy

Ocean energy is so plentiful that some researchers predict energy derived from ocean waves alone could generate more than the current world energy demand. But most of the technologies that can efficiently utilize this hidden energy in oceans are still in early stages of development. In some optimistic research reports the potential for renewable energy generated from the ocean is estimated to be as high as seven thousands E Joules per year (7,000 EJ/year) (Rogner et al. 2000), while others predict that it will only be about seven E Joules per year (7 EJ/year) (Sims et al. 2007). Predictions aside, the records show that at the end of year 2009, the worldwide, installed capacity of the ocean generated power has been less than 300 MW (Lewis et al. 2011).

Current major conceptual energy extraction technologies from the ocean are the use of the ocean waves and currents, vertical (most of the current actual generated power is by utilizing this method) and horizontal movement of the ocean water due to what is known as tidal effects, ocean thermal conversion, and salinity gradient.

When the wind comes in contact with the ocean surface creates two different movements on the body of the water. The body of water either is pulled up or pushed forward with the wind. The action of water pulling up creates a potential energy in water that if it is captured when the water comes back down can be useful for power generation. Also the action of pushing water forward can cause utilization of this kinetic energy in generation of power. All these kinetic and potential energies can be utilized to generate power and electricity if the proper technology is implemented.

Ocean tides are another energy source that is generated due to the combination of the inertial, centrifugal, gravitational and rotational forces acting among the Earth, the Moon, and the Sun. When the alignment of the Sun, Earth and Moon changes from all being located on the same direction to a condition that direction of lines that connect each two of them together are perpendicular to each other, the changes in combined forces among them cause the tides height changes between the maximum height and the minimum height extremes. This continuous up and down movement, in conjunction with the configuration of the ocean bed near the location of the tides, generates another horizontal movement for the body of the ocean water. These movements also can be the resources for generating power and electricity by utilizing proper technologies.

Also due to low thermal conductivity of the sea water almost all of the thermal energy received from sun and absorbed with the water stays in the upper layers of the ocean water. Very small portion of this heat is transferred to the lower layers of the ocean, and therefore this condition creates a differential temperature level between the upper and lower layers of the ocean water. With proper technology this temperature difference can be utilized for generating power and electricity as well.

Finally, salinity gradient (Osmotic power) which is the difference in concentration of salt in seawater and river (fresh) water can be also used for power and electricity generation. The potential methods for collecting this energy are reverse electrodialysis and pressure retarded osmosis. Both methods are based on potential of two fluids with different level of concentration of salt to come to a balance of concentration acting on two sides of a membrane. For a detail discussion on all aspects of ocean energy see (Lewis et al. 2011).

12.7 Sum-Zero Energy Buildings

The concept of Sum-Zero Energy Building (SZEB) has been looked at from different point of views and has defined with dissimilar targets in different literatures. For example when the target of the building energy consumption evaluation is to provide enough renewable energy on the project site to offset all the site's yearly demand, it is referred to as the whole building site energy consumption, but when the target of the evaluation is to include enough renewable energy on the project site to offset the total energy used for generation and delivery of the yearly energy demand of the building including its site to the site, it is known as the source energy consumption. A SZEB also have been referred to a building that the cost of the energy for the owner is at least equal to the money that the energy grid provider pays to the building owner for the amount of the energy that his building delivers to the grid. Finally in some literatures an SZEB has been defined as a building that produces at least enough emission-free renewable energy to cover the emission generated by its non-renewable energy sources.

Before going any further, let's discuss the difference between the source and site energy with a little more detail. As it was said earlier, site energy is basically the amount of the energy that has been brought to the site and the source energy is the total energy used to produce and transfer the energy to the site. Since each region has a different structure for energy delivery and also uses different resources and also equipment to generate electricity (as an example), therefore the conversions used for calculating the proper multipliers for source energy calculation is different in each region. For simplicity and ease of understanding let's assume the only source of energy which is used in a building is electricity and the annual energy consumption of the building is 100,000 kW h. The site energy can be calculated by simply converting this 100,000 kW h to its equivalent in terms of kBtu. No matter where in the country this building is located, we can use this conversion to calculate its site energy (e.g. the site energy for this building will be equal to 100,000 kW h × 3.413 kBtu/kW h or 341,300 kBtu).

Now assume this building is located in a region with a Source Energy Factor (SEF) of 8.05. (The electricity source energy factor is defined as heat input in MMBtu/net generation in MWh, and as it was said earlier is different from one region to another due to their different structure for energy delivery and also use of different resources and equipment to generate the targeted energy type.) Therefore if this building still consumes 100,000 kW h electricity per year, then its source energy will be calculated by multiplying the electricity consumption by the source energy factor for that region. That will results in 100,000 kW h × 8.05 kBtu/kW h or 805,000 kBtu. If this building was located in another region with source energy factor of 6.08, then its source energy could be calculated as 100,000 kW h × 6.08 kBtu/kW h or 608,000 kBtu.

Implementing each of the discussed strategies in defining the concept of SZEB and therefore calculating the total energy consumption of the building based on that specific definition obviously has its own positive and negative associated issues.

The notable characteristics of a site SZEB method are its ease of implementation, measurement, and understanding, while there is a lack of accountability for non-energy related differences between different fuel types, such as its availability and source distance to the site or the quantity of the generated pollution.

On the other hand the most notable characteristics of the source SZEB, is that by using this method it is possible to include the energy value of different fuel types used at site in the calculations, and it is easier to reach zero energy by this method.

Typically the cost SZEB is easy to implement and measure, but at the same time it is very difficult to track the rapid energy source price changes.

Finally the emission SZEB requires proper means of emission eliminating techniques that in some cases could add to the cost of the building considerably, while it provides easier path of reaching SZEB, and capability of factoring in non-energy differences among different fuel types in the energy evaluation of the building.

Independent of what definition and strategy is chosen to define a SZEB, there are always specific techniques and strategies to be employed in order to create on site renewable energy. These techniques can not only cut the dependency of the building on the energy provided to it by the electricity grid or other utility providing resources, but also can eliminate the carbon emission of the building as well. Of course all these techniques and strategies have a direct relation to the location of the building and the available natural sources of energy in that region, such as year around availability of energy from the Sun, ocean, or wind.

A Building capable of providing a yearly energy quantity more than what it uses and therefore allows its owner to sell the residuals back to the electricity grid is usually called energy-plus buildings and a building that is capable of generating energy just short of its yearly energy requirement and therefore at least for a few percent of its energy is dependent on the electricity grid is called a near zero energy building.

It is obvious that designing and operating a sum zero energy house is much simpler than designing and operating a sum zero energy commercial building. A house is usually only dependent on energy for a limited number of appliances such as heating and cooling units for extreme outdoor conditions. Other energy consuming elements in a house are kitchen appliances, lighting throughout the house, television, computer, etc. Of course other than losing the functionality of the heating equipment in some rare locations and occasions the loss of the functionality of a house is not as critical as a loss of functionality of equipment or appliances in a commercial building. Some commercial buildings rely on cooling system on a 24 h basis during the week for places such as central computer rooms, electrical rooms or elevator machine rooms. The whole business profitability of some manufacturing sites depends on year around access to reliable source of energy. Loss of such functions can have a hard negative effect on the businesses in these buildings. Therefore even the best sum zero energy commercial buildings should have grid-dependent backup source of electricity or other source of energy as it is suitable. Means for storing the excessive generated energy should be provided to store the generated excess renewable energy and later use it when the original source of energy is not available anymore.

Some of the advantages of the SZEB are eliminating the possibility of the future energy cost increases for the owner, and improving the energy efficiency of the building and therefore reducing the long term cost of ownership and living.

On the other hand some of the disadvantages of SZEB are higher initial cost and possibility of dependency on the grid on the same time of the peak demand in the grid.

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Part VI
Uncertainty and Risk Management

Chapter 13
Uncertainty and Risk Management

13.1 Probabilistic Versus Deterministic Simulation

The primary purpose for performing an energy modeling for a building and its systems is to predict the future energy consumption of the building. To perform an energy modeling simulation, in addition to the need for keying in all the physical dimensions, orientation and constructing elements characteristics of the building, it is required to enter almost all the building constructing elements and their thermal characteristics, and all the utilized systems and their required enabling power for operation and level of efficiencies, into the model as input. Available commercial simulation software uses its underlying mathematical structure and executes proper calculations with this information to provide a single estimated output which represents the total building yearly energy consumption level.

The simulation software therefore performs a deterministic procedure, assuming, e.g., all the material that actually will be used in construction of the building has the exact heating characteristics, and all the utilized systems in the building hold the exact energy efficiency levels that has been assigned to them by the modeler. To some extent these are legitimate assumptions, since to the best of their efforts, the architect and engineers supervise the purchasing and installations of all the building elements and systems according to the specified specifications in building design construction document. But is that enough?

In reality, when the architect through the building design specifications e.g. specifies a certain type of stone that has a specific heating characteristics (U-value) to be used as one of the building façade constructing elements, even though the suppliers provide material with the exact heating characteristic as it was indicated in design specifications, this does not mean that every single face stone installed in the project has the exact same characteristics. Actually it might even be correct to say that almost none of the used surface stones have the same exact characteristics as it was specified. This is due to lack of complete accuracy in testing condition and testing apparatus utilized by the different manufacturers during the production of surface

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stones. Of course there are many agencies and standards that regulate how and under what conditions, manufacturers have to test and represent their product performances to the market. These products then will be labeled as products complying with the standard and therefore maintaining reliable performances.

But even these regulations cannot guarantee the exact product characteristics as what has been advertised due to the allowable tolerances in testing procedures. It is customary for all the testing and certifying standard agencies to allow some degree of deviation from the represented performance levels. For example assume AHRI 550 which is the standard for testing vapor compression chilling machines allows a test tolerance of 7.5 % for certified tested chillers at full load. Then a chiller manufacturer can represent its chillers with a specific efficiency of five tenth of kilowatts per ton (0.5 kW/t) (at full load), if they follow the required test procedure and the efficiency of their tested chillers fall within the acceptable range of 7.5 % of the advertised performance at full load (similar conditions are true in part load conditions). This means even a chiller with efficiency of up to 0.53 kW per ton can be qualified and labeled as a chiller with 0.5 kW per ton efficiency. Similar tolerances are allowed by different agencies for every other equipment and material utilized in the building construction and operation as well. Such deviations from the exact characteristics of the used materials and equipment efficiencies in the building from what has been used as input to the energy model provide ground for what is called uncertainty in energy modeling simulation output.

As I explained earlier one of the early steps in preparing an energy modeling simulation for a building is to enter the size and heat transfer characteristics of the building different envelope elements into the model, such as *U*-values of walls and roofs and *U*-value and shading coefficient of different building glazing elements. Of course the *U*-value of each wall or roof is calculated by combining the *U*-values of the material that are used to construct the wall or roof layer by layer, such as bricks, sheet rocks, and concrete. This data then along with other input data will be used by the energy modeling simulation software to calculate the hourly energy required for cooling or heating of the building throughout the year.

Since 1980s comprehensive academic efforts have been done to quantify the effects of uncertainty in the building energy modeling specifically on a ground of uncertain envelope element's heating characteristics of the buildings.

In 1990, Clarke, Yaneske, and Pinney in their paper "The harmonization of thermal properties of building materials" (Clarke et al. 1990) represented data regarding the variations of the building construction material properties with moisture content, and also the resulted uncertainties in the manufacturer represented characteristics of different building materials. They showed that the range of thermal characteristics of the construction material which are really used in construction of the building can swing in considerable ranges from what has been selected during the design time. For example conductivity of calcium silicate cellular glass with density of 136 kg/m^3 when it is tested in different temperatures between 10 °C and 37.7 °C, can swing in a range of 0.047–0.051 W/m K. and copper conductivity as its density changes between 8,600 and 9,000 kg/m^3 changes in a range from 200 to 384 W/m K. This showed that the characteristics of the ultimately used material in the building can have a considerable deviation from the selected and used material characteristics in original energy modeling during the design stage.

In 2010, Dominguez-Munoz, Cejudo-Lopez and Carrillo in their paper "Uncertainty in peak cooling load calculations" (Dominguez-Munoz et al. 2010) represented the effects of multiple (more than 25) input components on the overall cooling system output. They showed that the peak cooling load uncertainty due to effects of the chosen input elements could be as high as ±15 %. It should be noted here that the possibility of occurrence of the peak cooling load below 4 % and above 96 % of the mean value was shown to be extremely small and almost negligible.

Prior to that in 2002, McDonald in his PhD thesis "Quantifying the effects of uncertainty in building simulation" (McDonald 2002) showed for a specific office building and based on the defined uncertainties (20 %) in input parameters such as conductivity of external wall insulation, and conductivity of external wall brick face the calculated energy consumption standard deviation was ±7.77 kW h.

In 2012, in my PhD thesis "The effects of sub-optimal components in cooling systems energy consumption and efficiency" (Khazaii 2012) I showed the envelope elements of the building are not the sole sources of uncertainty in energy consumption of the building and other parameters such as testing agencies test tolerances allowance for testing the HVAC equipment have considerable impact on the output probability distribution of the energy consumption of the whole building. Of course there are other uncertain elements that could be added to this process, such as lighting power (watt) tolerance allowance, which was missing from my research, and could make the results even more considerable.

These researches show the importance and need of new approach in energy modeling different from the current industry-wide adopted method, and introduction of new revisions to the existing software for building energy modeling simulation to make it capable of performing a probabilistic energy modeling instead of current deterministic method. The above mentioned researches also show the need for emphasizing on the fact that the commercial software writers should get themselves familiar with the relevant concepts such as uncertainty and sensitivity and implement the required provisions in their software.

13.2 Implementing Uncertainty and Sensitivity Analysis in Energy Modeling

Uncertainty analysis and sensitivity analysis are two main topics in branch of science known as statistics. Unfortunately up to a few years ago these powerful tools did not find their ways into the building architecture and HVAC engineering world. As it was stated earlier in the past few decades there were some attempts on using these tools to disclose the effects of uncertain envelope elements on building energy consumption, but I believe very soon these concepts will be developed further and will be used more universally in building energy modeling and design.

For better understanding the concepts that are discussed in this section it is necessary to gain an adequate knowledge of the uncertainty and sensitivity concepts. Therefore I will briefly introduce the main concepts related to uncertainty and sensitivity analysis, and then describe how these tools can improve our energy conscious building design. For detail discussion on this subject see (Saltelli et al. 2008) and (Aven 2003).

13.3 Uncertainty and Sensitivity Analysis Definitions

By definition an uncertainty analysis (UA) is a tool that helps the modeler to study the changes in the output of his model when he changes the inputs to his model. The modeler gains multiple benefits from the uncertainty analysis. The most important advantage of performing an uncertainty analysis is that it can help the modeler to make better decisions by better understanding the system which is under investigation. This better decision making can be achieved from the fact that uncertainty analysis provides proper ground for more informed discussions and communications among the professionals whom are working on designing or improving a system by making quantified output values accessible for them.

Sensitivity analysis (SA) on the other hand is a useful method that helps the modeler to calculate the uncertain parameters which have the most influences on the outputs of the model. There are many apparent benefits to this type of analysis because once the most influential parameters in a model (system) are identified more attention can be placed on improving the real-life targets by improving the most effective elements of the system.

13.4 Uncertainty Quantification Techniques

In general two main approaches for quantification of uncertainty are known to be external and internal approaches; both of these rely on statistical techniques.

13.5 External Methods

In an external method approach the mathematical structure of the simulation software are assumed to remain unaffected. It means the methodologies that are used to calculate different outputs will not change. Instead here the external factors such as how does the simulator select the inputs and how does he describe the model are assumed to be changed. Therefore this method basically evaluates the effects of uncertainty from the outside of the simulation program. It means that in an external method in a computer simulation model, the simulator changes the input parameters by ignoring the simulation program's possible errors and approximations, and his goal is to implement and then evaluate the effects of some external changes on the model output.

The external methods are subdivided into local and global methods. In a local method the effects of change of an individual parameter on the uncertainty of the output of the model is evaluated, while in a global method the effects of change of multiple parameters on the uncertainty of the model is assessed. The notable similarity between the two approaches is that the correlation between the input and output for both methods are usually considered to be linear, while the main difference between the two different approaches is that the input parameters in local method are sampled one by one and the target is to understand the partial derivative of the output in relationship with the input, but in a global method the input parameters are sampled all together at the same time and the target is to understand the uncertainty of a specific input in relation to the overall outputs.

13.5.1 Local Methods

Local methods can be sub-categorized into differential sensitivity method and factorial method. A differential sensitivity analysis method is usually used to evaluate the effects of change of an individual input parameter on the uncertainty of the output. In this method generally three sets of simulations (1) with original input value, (2) with upper limit of input parameter, and (3) with lower limit of input parameter is performed and the results from these three sets of simulations will be analyzed to provide a better understanding of the effects of the individual parameter changes on the output of the model simulations. This method is easy to perform and interpret results, but the weakness of the method is that each input is assumed to be independent from all the other inputs.

In the factorial method, during the simulations all the uncertain parameters alter between either the upper and lower limits of input parameter or among upper limit, lower limit and mean value of the uncertain parameters, and then the results will be evaluated to provide a better understanding of the effects of the parameter changes on the output of the model simulations.

13.5.2 Global Methods (Sampling-Based Methods)

Typically in global methods the uncertainty in input parameters is used to determine the probability distribution of the output while all the variables are sampled simultaneously. In general the fundamental concept of all the sampling based methods is to generate and investigate an overall depiction of relationship between uncertain analysis inputs and uncertain analysis results. In another word each of the uncertain analysis results are functions of the uncertain analysis inputs, and uncertainty in uncertain inputs results in a corresponding uncertainty in the analysis outputs. These are the main concepts in uncertainty analysis (measuring the uncertainty (probability distribution) of $f(x)$ provided the uncertainty in x), and sensitivity analysis (importance of existing uncertainty in x with respect to the uncertainty (probability distribution) in $f(x)$).

Therefore in order to implement a sampling-based uncertainty and sensitivity analysis one should take a few steps. The obvious first step is to define a number of uncertain input elements along with their epistemic uncertainty distribution allocations. The next step is to propagate the input samples and to generate an association diagram or formula between the uncertain inputs and the analysis outputs. The final two steps would be to generate the uncertainty analysis results and then to investigate the most influential uncertain input or performing a sensitivity analysis.

Among the described procedure above the most complicated and also important one is assigning the proper probability distribution to the epistemic uncertain inputs. Proper assignment of these uncertainties not only helps to determine the uncertainty (probability distribution) of the outputs more accurately, but also determines the sensitivity of outputs to input parameters with higher reliability degree. Therefore it is important to spend enough time in order to be able to depict the best distribution match possible for each of these uncertain inputs. The time that is spent here is well worth and probably the most critical in reaching more reliable results.

The most common sample generation techniques are random sampling, importance sampling, Latin Hypercube Sampling, and Monte Carlo Sampling. Among them the most commonly used sampling methods are the Monte Carlo Sampling and Latin Hypercube Sampling due to their capability of performing analysis for the complicated systems with use of only a small number of sample sizes.

13.5.2.1 Monte Carlo Method

The most famous and widely used method of global category is Monte Carlo sampling method. In this method, all the uncertain parameters are perturbed by a random quantity before the next iteration is performed. Of course samples are more likely to be drawn from sections of the input distribution that are assigned to have more chance of occurrence. In this method the number of simulations and number of uncertain input parameters are independent from each other and an acceptable number of iterations as it is defined in different literatures are about eighty iterations (McDonald 2002). In the Monte Carlo method a risk analysis—by creating model of possible results based on substitution of the uncertain inputs from a range of values (probability distribution)—is performed. Each time a different set of random values are pulled from the different distributions and is put into the model, and as a result each time a new outcome is calculated. This process continues (based on number of specified iterations) and finally a probability distribution for the outcome will be generated (Khazaii 2012).

13.5.2.2 Latin Hypercube Sampling Method (Stratified Sampling)

In this method members of the population are divided into homogeneous segments before sampling. Every sample shall be assigned to only one group, and all the groups together shall create a whole body of possible samples. Then random sampling applies within each segment (Khazaii 2012).

Therefore the main difference between this method and Monte Carlo method is in their input data selection distribution. Experience shows this method usually requires less number of iterations than the Monte Carlo method.

13.5.2.3 Random Sampling

In this method samples are collected from a random collection such as random numbers from a database and will be scattered without any specific rules inside the sampling field. This method can create clusters (when samples are very close to each other) or gaps (when very little number of samples are taken from some regions.)

13.5.2.4 Screening Method

Screening method is a particular case of sampling based methods which deals with each input individually. It is also known as once at a time (OAT) method. After all the required data sequentially modified the designer evaluates the results and makes decision based on the comparison among the outputs.

13.5.2.5 Variance-Based Method

Variance-based methods are sampling-based methods that also depend on the computation of conditional variances. They allow a global, quantitative, and model-independent sensitivity measure. This method is known to be more complex than the other methods.

13.6 Internal Methods

These methods deal with conditions that the uncertainty is considered in the arithmetical equations of the model. Since these methods are shown to have not particular use in uncertainty analysis in building energy modeling, we will stop our description here.

13.7 Uncertainty Result Presentation

Presentation of uncertainty analysis results is usually simple and is only involved in displaying the generated output maps, calculated based on uncertain inputs. Some of the common presentation possibilities include means and standard deviations, density functions, etc. Displaying the results of a sensitivity analysis is usually more time consuming since it requires actual investigation through the maps to find the effects of each individual input on simulation output. The followings are a few approaches to sensitivity analysis presentations that usually can be seen as the representatives of the sensitivity analysis.

Scatter-plots: A plot of the points that can show the relationship between models inputs and outputs. Despite of the complexity of the system and its need for more advance technique for sensitivity analysis, the scatter-plot technique is a very good starting point for understanding the relation between model inputs and outputs.

Correlation: Correlation is the representative of linear relationship between input and output. Correlation Coefficient (CC) has a value between -1 and $+1$. Positive correlation between two factors means that as one increases or decrease the other will increase or decrease as well, and a negative correlation between two factors means as one increases or decreases, the other will decrease or increase accordingly.

Some of the other known approaches are regression analysis, partial correlation, rank transformations, statistical tests for patterns based on gridding, and top down coefficient of concordance (TDCC).

13.8 Types of Probability Distribution

13.8.1 Discrete Distribution

In a discrete distribution (Fig. 13.1) each possible choice has an exact possibility of occurrence and sum of all these possibilities should be equal to 1. The difficulty of this method is how to specify the exact probability of each choice. The discrete distribution can either be parametric or nonparametric but for both cases is bounded (i.e., there are a finite number of options).

13.8.2 Even Distribution

The best choice of distribution when we are working with systematic errors is even distribution (Fig. 13.2). In this bounded distribution which is a special case of discrete distribution the probability of occurrence of the variable throughout a possible range is equal.

Fig. 13.1 Discrete distribution

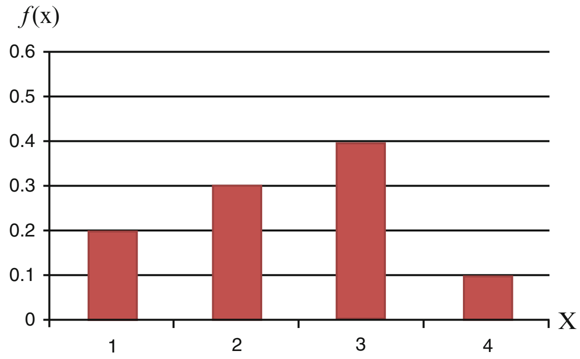
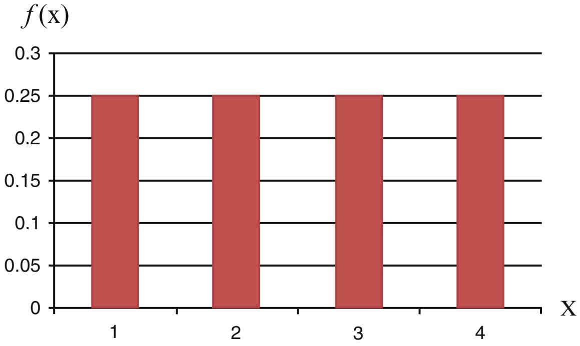


Fig. 13.2 Even distribution



13.8.3 Normal Distribution

The best opportunity for using the normal distribution (Fig. 13.3) which is an important and commonly used distribution is when the modeler purpose is to explain a physical data such as distance or temperature. In this method approximately 68 % of the probable values that a variable can take are within one standard deviation of the mean value, 95 % are within two standard deviations of the mean and 99.5 % within 3 standard deviations of the mean.

When mean value $\mu = 0$ and standard deviation value $\sigma = 1$ (variance value $\sigma^2 = 1$), then the distribution is known as standard normal distribution. Usually it is assumed that for normally distributed variables, combination of independent normally distributed random variables also distributed according to the normal distribution.

Random number generation for normally distribution function can be done based on different methods, e.g., trapezoidal method, polar method, and histogram method (McDonald 2002).

The normal distribution is often called Gaussian distribution or bell curve.

Fig. 13.3 Normal distribution

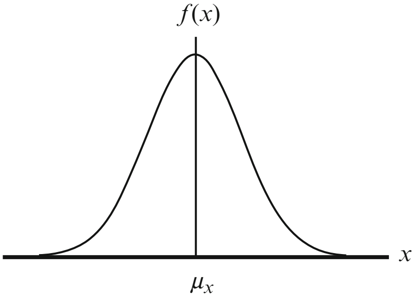
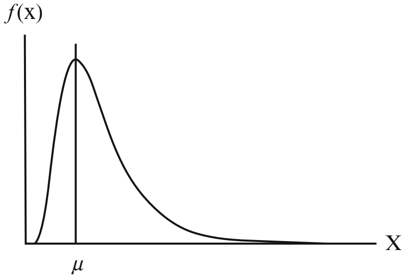


Fig. 13.4 Log normal distribution



13.8.4 Log Normal Distribution

This distribution is provided when two or more normally distributed parameters being combined to provide a single distribution. The log-normal distribution is the combination of two or more variables which are normally distributed.

Log-normal distribution (Fig. 13.4) is defined by two parameters of mean and standard deviation in log space. Other used names for log-normal distribution are Cobb-Douglas and anti-log-normal distribution. There are also other types of log-normal distributions that are characterized by more than two parameters (McLaughlin 1999).

13.8.5 Triangular Distribution

This distribution usually is useful when the choices are minimum, maximum and most likely value of some occurrence. The triangular distribution (Fig. 13.5) is a continuous distribution that is often used in fuzzy logic applications.

In a building simulation context it is a useful distribution because it is described by minimum, maximum and most likely values. For example, the typical use light in a space can be augmented by a minimum and maximum to characterize the possible range.

Fig. 13.5 Triangular distribution

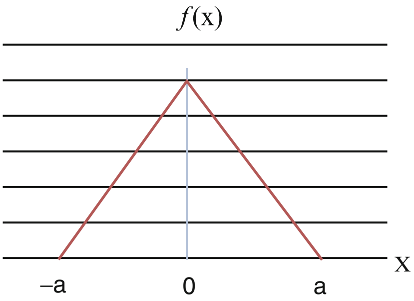
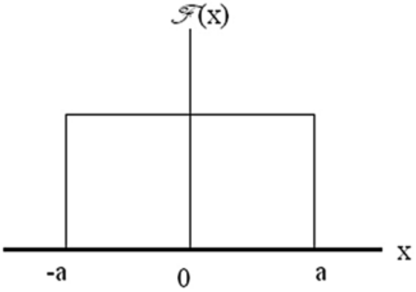


Fig. 13.6 Uniform distribution



13.8.6 Uniform Distribution

Uniform distribution (Fig. 13.6) is a subcategory of discrete distribution where a finite number of equally spaced values are equally likely to be observed; in other word every one of n values has equal probability of occurrence of $1/n$.

It is most useful in simulation where attention should be given to a poorly defined parameter, say at the early design stage. The distribution is the most suitable for modeling systematic errors as these errors are not random and hence the true value is equally probable throughout the given range (McDonald 2002).

13.9 Uncertainty in Energy Modeling

When we through an energy modeling exercise attempt to predict the cooling and heating systems energy consumption, it implies that we are making assumptions about the system components performances. These assumptions derive from our lack of knowledge (uncertainty) about how close to our expectations these components could actually perform. Therefore quantifying these uncertainties if it is possible, in fact can be very helpful for almost every group of people who are engaged and have role in design and construction of the building industry. Design engineers can use these quantified measures to select a better component and system and perform better design, building owners and energy contractors can have a more realistic energy cost prediction of their buildings, and code and standard writers can use the results in order to set meaningful barriers for achieving buildings energy efficiency goals.

As I said earlier, an uncertainty analysis is a procedure that helps the architect and engineers to realize the range, probability distribution and fluctuation of their model output (consumed energy) when they change the inputs to the model. They gain multiple benefits from the uncertainty analysis which among them the two most effectives are, making better decisions by better understanding the system and opening ground for discussion and communication for system improvement.

Also as it was said earlier, a complementary analysis to uncertainty evaluation is sensitivity analysis which is a method that helps to pin down the uncertain parameters which have the most influence on the simulation outputs. The most important benefit of this type of analysis is that after the most influential parameters are identified, higher level of attention can be focused on them to improve the outcome of model and therefore the design.

In past two decades, ASHRAE standard (ASHRAE 2013) in its "G" section has presented a modeling solution for comparison between a design building and an imaginary base-building similar to the design building with pre-determined HVAC systems along with other prescribed requirements. To comply with requirements of this standard and also in order to achieve LEED points for the design building, the energy cost of the design building model should be compared to the energy cost of the base-building. The higher the savings or the difference between the two outcomes is a higher number of LEED points in Energy and Atmosphere (credit 1) section will be achieved. In spite of the fact that implementing this solution has made an obvious positive impact on the achieved degree of savings on the energy consumption of the newly designed buildings, it can be argued that there is still room for improving this method for achieving even higher levels of energy savings by comprising the uncertainty measures as part of the modeling inputs. It also can be conferred that factoring uncertainty in this solution can prevent those buildings that are not really designed with effective energy saving measures from being certified as energy compliant buildings, or at least not to record high sustainability and efficiency scores. Of course that itself can be translated to even more net energy savings.

Generally when energy modelers use commercially available simulation software to perform a building energy modeling simulation, they enter numerous inputs into both design building and base-building models according to guidelines of ASHRAE standard (ASHRAE 2013). These inputs cover a wide range of different categories such as location of the building, building envelope material sizes and heating characteristics, internal loads, and HVAC system. Each of these inputs carries its associated quantity of uncertainty which if it is ignored (as it is being ignored in current practice) will reduce the reliability of the outcome of the modeling simulation exercise. To overcome this shortfall, in recent years as it was noted earlier in this chapter relatively large number of researchers have attempted to include the uncertainty resides in the building envelope material in modeling simulation and to predict its effects on the accuracy of the outcome of building energy consumption. In my PhD thesis “Effects of sub-optimal equipment of overall energy consumption and efficiency of the cooling systems” (Khazaii 2012) I quantified the effects of the allowable test tolerance of the HVAC equipment on the energy consumption of a few typical buildings when it uses a number of different HVAC systems. It was done on an excel based modeling platform, that I wrote to make the probabilistic simulation possible. In the same research I also presented that “G” section of the ASHRAE standard (ASHRAE 2013) champions the comparison between a design building (a real building subjected to the uncertainties) and a base building (an imaginary building and therefore not subjected to the uncertainties) energy consumption (cost). It can be argued that it would be a more accurate modeling exercise, if the energy modeling software be revised in such manner that it can perform a probabilistic simulation (including the uncertainty factors) for the design building, and a deterministic simulation (as it is currently done) for the base building, before comparing the two simulation results, and making decision regarding compliance of the design building with the standard requirements. Without these changes to the software and the standard there is always risk of scoring energy saving credits for a building (in comparison with the imaginary building) which it is in fact not going to be realized in the real world.

13.10 Risk Management and Decision Making

What I have discussed in this final chapter and up to this point could become the source of information and therefore basis for multiple new ideas and solutions. Risk management and decision making which are the immediate benefits of uncertainty and sensitivity analyses can be the sources of estimation of the future performance, or future energy cost of any building. Of course one may say people all over the industry are making decisions every day and as everybody knows every decision making naturally involves some level of risk taking. That is correct, but what I mean in this chapter is not a simple blind risk involved decision making. It is actually an educated risk taking act based on quantified allocated risks to each action. As an example, assume the commercial software is fully developed in a manner that designer can include the uncertainty of all the aspects of the building accounted into the energy model. By doing this the designer can take the results of probabilistic energy modeling of his building and use that to predict the probability distribution of the energy consumption and cost for that building in any future period of time. Such information could be very valuable since it can be communicated with a simple language containing percentages and numbers. Generally people tend to make better decisions when they are given the opportunity of knowing how much risk they are asked to take.

It should be noted here that uncertainty analysis is different from decision analysis that demands its own lengthy attention, which its complete discussion is out of our scope here. As it was described earlier, at the end of an uncertainty analysis we get a probability distribution of the outcome in question. Different people with different attitudes may make different and still all correct decisions based on a performed uncertainty analysis. In different literatures, there are many different proposed methods of decision making under uncertainty, each using their own decision criteria. Decision criteria such as maximin expected utility, reliability weighted expected utility, optimism-pessimism index, etc. Each of these methods rely on some kind of utility value that is used to help the decision maker makes his decision in selecting the proper option (in our case the system with the lowest energy consumption value). A utility function is a function that relates the level of risk taking of a decision maker with his possible gain.

Let's try to see how a typical decision could be made after a probabilistic energy modeling has been done by utilizing decision trees and utility functions. A decision tree starts with a problem or question as the beginning node or starting point and depending on the number and complexity of the decision possibilities develops to a multi branch tree. First group of these branches out of the original point represent the possible different decisions that could be made and carry the percentages showing the possibility of each decision compared to the rest of the decisions. Therefore if there are only two possible options to choose and each option has equal probability there will be only two lines at the starting point that each will carry a 50 % possibility tag and the possible values at the end of each line. Other tree branches will be added to the end of each primary branch to show the percentage possibility and the value represented by that percentage, and so on.

Let's assume the original question is the cost of an office building (133,600 ft^2 in Atlanta) HVAC system and its next 5 years energy consumption, and we have made two sets of probabilistic energy modeling for this building based on two different HVAC systems. First system a traditional variable air volume system and the second system a ground source heat pump system. Also let's assume the results of the probabilistic energy modeling for energy consumption of two systems are shown in bell shape distributions that can be simplified in three simple outputs with 16 %, 68 %, and 16 % chance for 0.83 $\$/\text{ft}^2$/year, 0.93 $\$/\text{ft}^2$/year, and 1.03 $\$/\text{ft}^2$/year and 0.63 $\$/\text{ft}^2$/year, 0.73 $\$/\text{ft}^2$/year, and 0.83 $\$/\text{ft}^2$/year respectively. Additionally assume based on the previous project experiences the first cost for HVAC system installation for these systems can be defined simply as 40 % and 60 % chance for 26 $\$/\text{ft}^2$ and 29 $\$/\text{ft}^2$ and 34 $\$/\text{ft}^2$ and 37 $\$/\text{ft}^2$ respectively. Furthermore assume a yearly increase in energy cost for both systems to be identical in 80 and 20 % chance for 8.5 and 7 %. Using the above information and the following utility function

$$\text{Utility Function} = (\text{Maximum Attribute} - \text{Selected Attribute}) / (\text{Maximum Attribute} - \text{Minimum Attribute}) \quad (13.1)$$

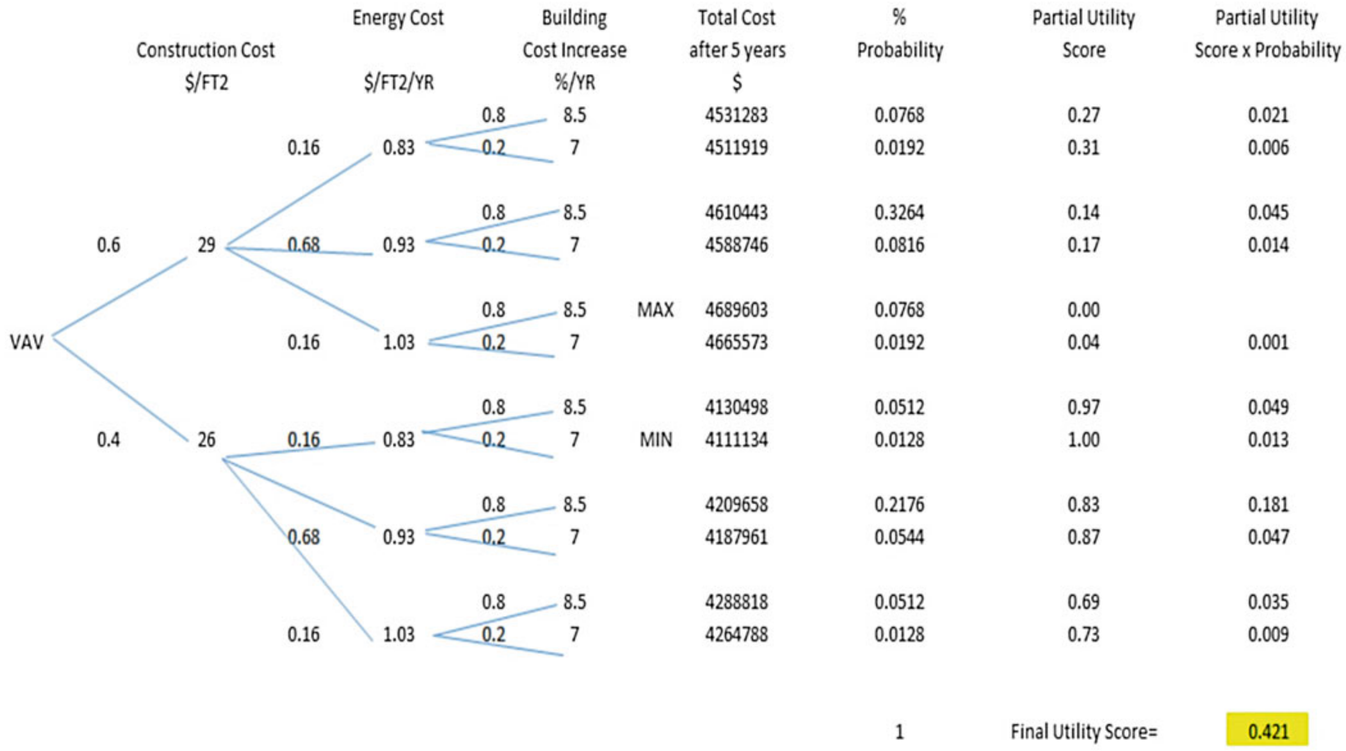
and probability of each option we can calculate the total utility scores of two systems to select the best possible choice between two selected systems, which of course is the system with higher total utility score (see Figs. 13.7 and 13.8). {When you look at the partial utility score column you can see the maximum and minimum costs in total cost column are correspondent with zero and one values, with maximum cost the least desirable and minimum cost the most desirable conditions. Therefore the higher the final utility value the more desirable condition you have}. Of course in this case both systems resulted in almost identical utility scores. Now assume we have changed the problem target from 5 to 10 years total cost estimate (including the first cost) (see Figs. 13.9 and 13.10). This time the utility factor of ground source heat pump is more clearly higher than traditional variable air volume system. It shows when we change our target to a longer time horizon the ground source heat pump will become more desirable, due to its lower energy consumption cost.

We have used Eq. (13.1) because we are working with condition of "economic bads" such as energy consumption, energy cost, etc. In conditions that we are dealing with "economic goods" such as environment quality or savings we have to use another version of utility function equation. Equation (13.2) is used for such conditions:

$$\text{Utility Function} = \left(\text{Selected Attribute} - \text{Minimum Attribute}\right) / \left(\text{Maximum Attribute} - \text{Minimum Attribute}\right) \tag{13.2}$$

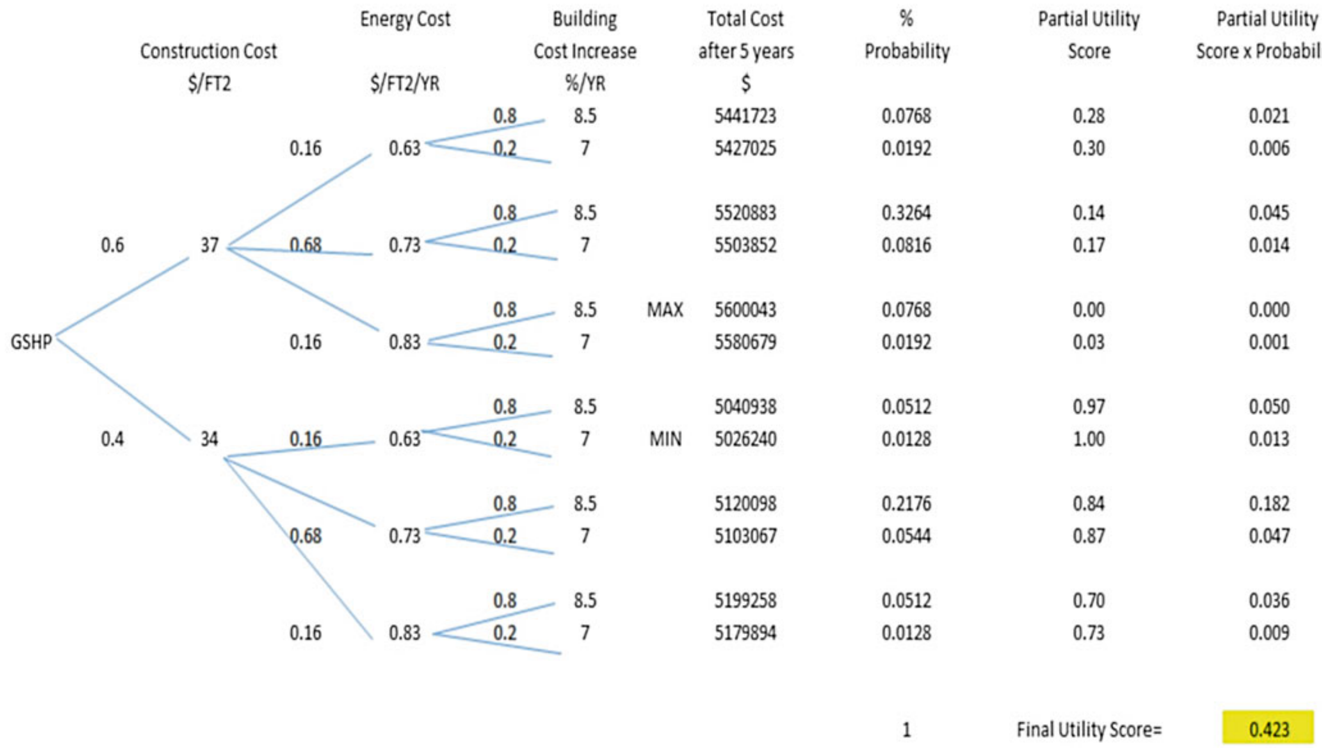
Equations (13.1) and (13.2) are proper when there is no risk tolerance included in the decision maker's decision. Other versions of the utility function can be used for conditions that the decision maker has some level of risk tolerance.

As the final word I would like to say that there is an obvious need for improving the way that building designers perform building energy modeling simulation. The current deterministic modeling which is being performed via using the available commercial energy modeling simulation software lacks the capability of factoring-in the multiple uncertainties in the input elements into the energy consumption output results. As a consequence considerable deviation in calculated energy consumption could be translated to inaccurate scoring standards and therefore more wasted energy than what it could be if the proper probabilistic calculations was done. Therefore the main purpose of this section is to shed light on an important missing factor from current energy modeling simulation and rating approaches and bring the attention of the HVAC professional community of practice to the necessity of making revisions to the current commercial energy modeling simulation software based on a factor (uncertainty) which at this time is almost completely ignored from their calculations. This approach can improve the process of decision making for the design and construction of the buildings which if it is implemented would have a considerable energy saving effect throughout the industry.



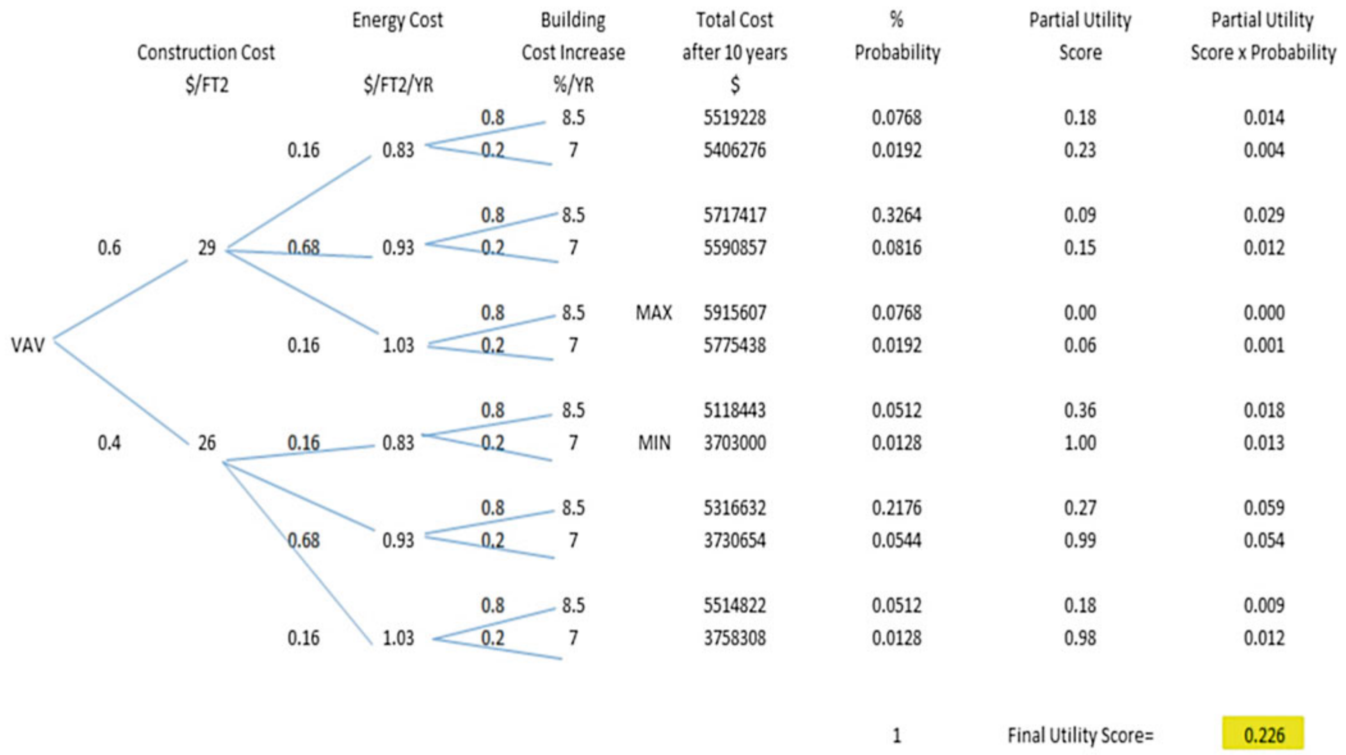
	Construction Cost $/FT2		Energy Cost $/FT2/YR		Building Cost Increase %/YR		Total Cost after 5 years $	% Probability	Partial Utility Score	Partial Utility Score x Probability
0.6	29	0.16	0.83	0.8	8.5		4531283	0.0768	0.27	0.021
				0.2	7		4511919	0.0192	0.31	0.006
		0.68	0.93	0.8	8.5		4610443	0.3264	0.14	0.045
				0.2	7		4588746	0.0816	0.17	0.014
		0.16	1.03	0.8	8.5	MAX	4689603	0.0768	0.00	
				0.2	7		4665573	0.0192	0.04	0.001
0.4	26	0.16	0.83	0.8	8.5		4130498	0.0512	0.97	0.049
				0.2	7	MIN	4111134	0.0128	1.00	0.013
		0.68	0.93	0.8	8.5		4209658	0.2176	0.83	0.181
				0.2	7		4187961	0.0544	0.87	0.047
		0.16	1.03	0.8	8.5		4288818	0.0512	0.69	0.035
				0.2	7		4264788	0.0128	0.73	0.009
								1	Final Utility Score=	0.421

Fig. 13.7 Utility score for VAV example (1)



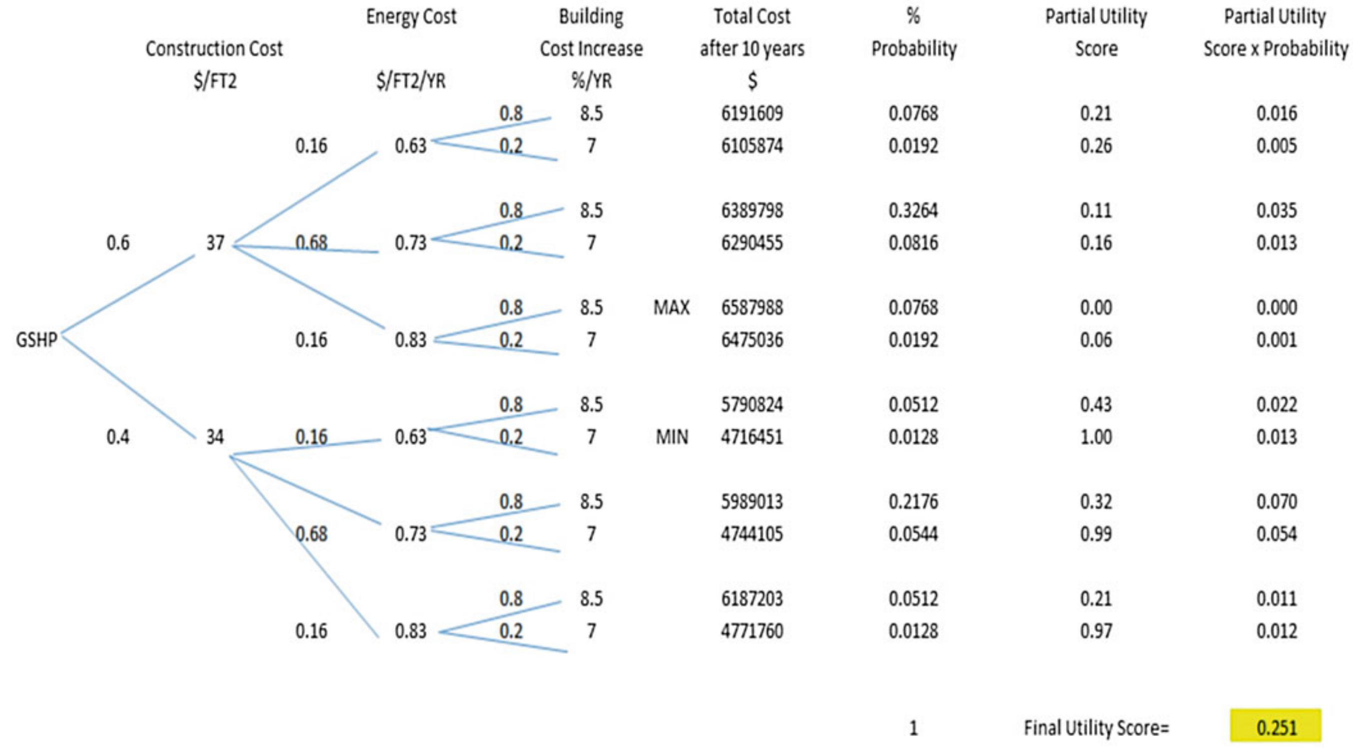
		Construction Cost $/FT2		Energy Cost $/FT2/YR		Building Cost Increase %/YR		Total Cost after 5 years $	% Probability	Partial Utility Score	Partial Utility Score x Probability
GSHP	0.6	37	0.16	0.63	0.8	8.5		5441723	0.0768	0.28	0.021
					0.2	7		5427025	0.0192	0.30	0.006
			0.68	0.73	0.8	8.5		5520883	0.3264	0.14	0.045
					0.2	7		5503852	0.0816	0.17	0.014
			0.16	0.83	0.8	8.5	MAX	5600043	0.0768	0.00	0.000
					0.2	7		5580679	0.0192	0.03	0.001
	0.4	34	0.16	0.63	0.8	8.5		5040938	0.0512	0.97	0.050
					0.2	7	MIN	5026240	0.0128	1.00	0.013
			0.68	0.73	0.8	8.5		5120098	0.2176	0.84	0.182
					0.2	7		5103067	0.0544	0.87	0.047
			0.16	0.83	0.8	8.5		5199258	0.0512	0.70	0.036
					0.2	7		5179894	0.0128	0.73	0.009
									1	Final Utility Score=	0.423

Fig. 13.8 Utility score for GSHP example (1)



		Construction Cost $/FT2		Energy Cost $/FT2/YR		Building Cost Increase %/YR		Total Cost after 10 years $	% Probability	Partial Utility Score	Partial Utility Score x Probability
VAV	0.6	29	0.16	0.83	0.8	8.5		5519228	0.0768	0.18	0.014
					0.2	7		5406276	0.0192	0.23	0.004
			0.68	0.93	0.8	8.5		5717417	0.3264	0.09	0.029
					0.2	7		5590857	0.0816	0.15	0.012
			0.16	1.03	0.8	8.5	MAX	5915607	0.0768	0.00	0.000
					0.2	7		5775438	0.0192	0.06	0.001
	0.4	26	0.16	0.83	0.8	8.5		5118443	0.0512	0.36	0.018
					0.2	7	MIN	3703000	0.0128	1.00	0.013
			0.68	0.93	0.8	8.5		5316632	0.2176	0.27	0.059
					0.2	7		3730654	0.0544	0.99	0.054
			0.16	1.03	0.8	8.5		5514822	0.0512	0.18	0.009
					0.2	7		3758308	0.0128	0.98	0.012
									1	Final Utility Score=	0.226

Fig. 13.9 Utility score for VAV example (2)



		Construction Cost $/FT2		Energy Cost $/FT2/YR		Building Cost Increase %/YR		Total Cost after 10 years $	% Probability	Partial Utility Score	Partial Utility Score x Probability
GSHP	0.6	37	0.16	0.63	0.8	8.5		6191609	0.0768	0.21	0.016
					0.2	7		6105874	0.0192	0.26	0.005
			0.68	0.73	0.8	8.5		6389798	0.3264	0.11	0.035
					0.2	7		6290455	0.0816	0.16	0.013
			0.16	0.83	0.8	8.5	MAX	6587988	0.0768	0.00	0.000
					0.2	7		6475036	0.0192	0.06	0.001
	0.4	34	0.16	0.63	0.8	8.5		5790824	0.0512	0.43	0.022
					0.2	7	MIN	4716451	0.0128	1.00	0.013
			0.68	0.73	0.8	8.5		5989013	0.2176	0.32	0.070
					0.2	7		4744105	0.0544	0.99	0.054
			0.16	0.83	0.8	8.5		6187203	0.0512	0.21	0.011
					0.2	7		4771760	0.0128	0.97	0.012
									1	Final Utility Score=	0.251

Fig. 13.10 Utility score for GSHP example (2)

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