

BUILDING SYSTEMS ANALYSIS AND RETROFIT MANUAL



**SHEET METAL AND AIR CONDITIONING CONTRACTORS'
NATIONAL ASSOCIATION, INC.**

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SECOND EDITION – MARCH, 2011



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NATIONAL ASSOCIATION, INC.**

**4201 Lafayette Center Drive
Chantilly, VA 20151-1219
www.smacna.org**

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NATIONAL ASSOCIATION, INC.**

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FOREWORD

This second edition updating and revision of the Retrofit manual comes at a time when green building guidelines, standards and codes are either recently finished or nearing completion. These guidelines, standards and codes are markers on the road to a sea change toward new approaches in new building construction. While these new green guidelines, standards and codes also apply to major renovation of existing buildings the focus is on new construction and little has been published to address the much larger issue of energy efficiency in existing buildings.

Historically, new buildings have added less than two percent to the total inventory of commercial buildings in the United States on an annual basis. For meaningful energy use reductions to occur on a national scale, the energy efficiency of thousands of existing buildings must be improved significantly. For the United States to make major progress in reducing its national energy consumption, most, if not all of the existing buildings must use far less energy.

Characteristics of all the green codes and standards are that public transportation be accessible nearby and that new land—greenfields—development is discouraged. Existing buildings are often located near public transportation and development typically occurs on a building's existing footprint. These two “greening” drivers may combine with basic economic factors to produce a compelling incentive for many prospective building owners to choose renovation of an existing building over the construction of new facilities.

The other factors that will help drive the retrofit and upgrade of existing buildings is the rising cost of energy and fuel. As other countries compete more fervently for the world's available fuels, higher prices are inevitable. Payback periods and return on investment intervals will shrink sufficiently to more easily justify capital outlays on the most energy efficient buildings; resulting in modifications to building envelopes, HVAC, plumbing and electrical systems.

The members of the *Building Systems Analysis and Retrofit Manual* task force have shared their expertise in the belief that other contractors will consider and enter the promising field of retrofitting and upgrading existing buildings. Readers of this manual are encouraged to submit additional thoughts and ideas to SMACNA's Technical Resources staff to further add to the building science and art presented in this manual.

SHEET METAL AND AIR CONDITIONING CONTRACTORS'
NATIONAL ASSOCIATION, INC.



BUILDING SYSTEMS ANALYSIS AND RETROFIT TASK FORCE

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CHAPTER 1

INTRODUCTION

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1.1 RETROFIT CONTRACTOR REQUIREMENTS

Contractors interested in the retrofit market should consider taking on the role of general contractor (GC). Building owners will prefer one point of contact and it needs to be the retrofit contractor. The retrofit contractor should arrange for and coordinate any subcontracting work needed to complete all the upgrades of the retrofit project. Many retrofit projects will require drawings that are sealed by a registered professional engineer (PE). If a PE is not employed by your firm, consider establishing a business relationship with one.

The costs of retrofit projects will have to be justified to the owner. Become familiar with return on investment (ROI) and life-cycle cost (LCC) analysis by reading the chapter on that topic in the SMACNA's *Energy Systems Analysis and Management* manual. An excellent resource for computer programs related to building energy and retrofit analysis can be found on the Department of Energy (DOE) website. Use one of the online computer programs to show the owner the impact of recommended retrofits. Keep it simple. Explain and show the operational and reduced maintenance benefits, life-cycle costs, monthly and annual energy or water savings, and return on dollars invested in building upgrades.

1.2 RETROFIT MARKET

The retrofit market is a multibillion dollar opportunity that has great upside potential as building owners become familiar with concepts such as sustainability, green building, energy savings, and commissioning. Take a look at the existing buildings in your community and service area. What is the general age and condition of those buildings?

In the commercial market retrofit opportunities are most likely to arise during or because of the following events: equipment failures, equipment obsolescence, energy savings initiatives, building purchases, tenant improvements, rebuilding, and building renovation.

1.2.1 Equipment Failure

Equipment failure accounts for over 85 percent of the retrofit market. Repairing or replacing equipment is an opportunity to expand into other retrofit opportunities. How the customer perceives the results and is treated will dictate whether this is a one-time or an ongoing business relationship with recurring opportunities.

1.2.2 Equipment Obsolescence

The size of the equipment obsolescence market is unknown since it falls in both categories of equipment failure and energy savings. Equipment obsolescence may be a leaking chiller that uses a CFC refrigerant, it may be a high-energy user like an old multizone system, or it could be a VAV system with failed or poorly functioning pneumatic actuators.

It is unlikely the customer will consult an HVAC contractor specifically about equipment obsolescence. This opportunity is more likely to reveal itself to the retrofit contractor when performing an energy savings walk-through, during an equipment repair, or when replacing equipment or controls due to failure or comfort complaints. There is great opportunity for the retrofit contractor to profit from obsolete equipment if the retrofit contractor trains its staff to recognize equipment that is outdated or inefficient and to bring that to the owners' and contractors attention. Equipment obsolescence is essentially an energy savings retrofit that is identified by the retrofit contractor instead of the customer.

1.2.3 Energy Savings

This accounts for less than 15 percent of the retrofit market but represents one of the areas of greatest potential growth. Approximately 80 percent of owners that have had an HVAC equipment retrofit had the retrofit due to an energy audit or commissioning. Therefore, the retrofit contractor should be familiar with the process of conducting an energy audit and the commissioning process.

1.2.4 Building Purchases

When a building is purchased it is very likely that it will at least undergo changes and possibly substantial upgrades to match the requirements of the new owner. This is a key opportunity for HVAC contractors to meet the new owner and spend a few minutes looking at the facility and offering preliminary suggestions regarding HVAC system enhancements and equipment upgrades. *Note: Certain future Model Building and Energy Codes may mandate an energy audit and commissioning be conducted within one year of the sale of an existing building.*

1.2.5 Tenant Improvements

Tenant improvements are often "invisible" from outside the building. The improvements may be a simple reconfiguration of existing space or the addition of a loading or staging area to serve growing material man-



agement needs. Often, tenants improve the space as a result of increasing or new business. Tenants may initiate contact with an HVAC firm as a request to add or move a supply register or relocate HVAC equipment.

1.2.6 Rebuilding

In the context of this manual rebuilding is when an existing building or building site is being repurposed for a new or expanded business proposition. In many rebuilding projects the only existing part of the building that is reused is the building shell—the walls and roof. In these cases, there are often opportunities for entirely new mechanical and roofing systems, fenestration, electrical upgrades, plumbing system reconfigurations and upgrades, etc.

Under many “green” building program restrictions, existing building may be the only way to be certified as a green building in areas that are not served by public transportation or near a wide range of services. Older buildings near the edge of towns and cities and in rural areas fit this profile. The desire to own green buildings will create a lot more activity among these types of buildings.

1.2.7 Building Renovation

Buildings are often renovated to accommodate new tenants, serve changing needs in the immediate area used by a tenant, or simply to reduce energy and water use. Growing, successful businesses are likely instigators of renovations.

1.3 ABOUT THIS MANUAL

This manual is divided into chapters that address the major categories of retrofit work:

- Commissioning
- Electrical
- Building Envelope
- Water Usage and Efficiency
- HVAC System
- Building Automation Systems and Controls
- CFC and HCFC Changeouts
- Customer Identification Retrofit Opportunity

It is not necessary that the retrofit contractor be an expert in all facets of retrofit work. It is perfectly accept-

able to subcontract much of the retrofit work and act as the general contractor.

The following sections summarize the contents of each chapter subject.

1.3.1 Commissioning (Chapter 2)

Commissioning is more than testing, adjusting and balancing (TAB) work. Commissioning is making sure the designer’s original intent for the building’s performance regarding indoor air quality (IAQ), ventilation, heating load, cooling load, and building management systems and controls are meeting the owner’s needs. Commissioning may be performed for a building that was never commissioned, or it may be performed for a building that has had building utilization changes due to changes in building occupants or usage. Having the building commissioned will document and summarize the changes and retrofit needs required. Commissioning is often performed by a third party so there will be no question of bias.

1.3.2 Electrical (Chapter 3)

A licensed electrician will be required to perform some of the retrofit work recommended in Chapter 3. If one is not on staff then partnering with an electrical contractor makes sense for current and future work. Chapter 3 discusses variable frequency drives (VFDs), peak demand, load shifting, lighting lamp replacement, and electrical motor upgrades.

1.3.3 Building Envelope (Chapter 4)

The building envelope is comprised of the roof, outside doors and windows, skylights, exterior walls, slab and all envelope joints. The building envelope protects the occupants from the outside elements and provides a protected thermal environment. It has a direct and significant impact on the building’s energy use, and building energy codes have specific requirements for critical envelope components. Use of a thermographic camera and non-contact thermometer are valuable tools when inspecting an existing building’s envelope.

1.3.4 Water Usage and Efficiency (Chapter 5)

In many buildings, up to 70% of non-potable water use is being met with potable water. Significant savings can result from meeting those needs with lesser quality non-potable water.

Domestic water and conservation retrofits include reducing water usage by installing automatic flush

valves, high efficiency water heaters and toilets, solar water heaters, sensor operated fixtures, faucet aerators, and similar flow restriction devices. These types of upgrades are generally initiated by the customer or recommended by the retrofit contractor. Some water utilities have incentive programs to encourage water conservation. With basic plumbing skills and knowledge of high efficiency products, the retrofit contractor can be prepared for this area of retrofit opportunities.

1.3.5 HVAC System (Chapter 6)

When retrofitting an existing building, minimize the supply airflow to reduce fan horsepower and energy consumption. Arbitrary use of air changes per hour to determine supply air quantities can waste energy. Airflow should be based on the sensible heat gain of the space which includes transmission and solar heat gain, people, lights, machinery, appliances, etc. As fan horsepower is proportional to the cube of the airflow, the energy savings is compounded with a reduction in the HVAC system airflow. Use of variable frequency drives (VFDs) is an excellent way to reduce electrical consumption of motors and often results in obtaining incentives and rebates. Another energy saving opportunity is to install a dedicated outdoor air system (DOAS), which takes advantage of free-cooling, helps meet new ventilation outdoor air requirements when that is required or desired, and provides other energy saving and operating benefits.

1.3.6 Building Automation Systems and Controls (Chapter 7)

Building automation systems (BAS) and controls replacement includes various retrofits including replacing pneumatic controls with direct digital controls (DDC), upgrading the BAS, and utilizing the ad-

vanced features of the BAS such as energy management, temperature setback, and occupancy sensing among others. BAS retrofit typically involves low-voltage wiring or wireless communications devices so an electrical contractor may not be required for BAS installations.

1.3.7 CFC and HCFC Changeouts (Chapter 8)

The retrofit opportunities for chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) changeouts are containment, conversion, replacement and modification. The options vary in relative cost and complexity. The age of the equipment and the availability and cost—or expected future cost—of the existing refrigerant will influence which retrofit makes sense. Replacing CFC and HCFC refrigerants with an HFC refrigerant requires following procedures outlined by the equipment and refrigerant manufacturers. The process includes evacuating existing refrigerant and oil, and replacing with appropriate and compatible oils and refrigerants.

1.3.8 Customer Identification Retrofit Opportunity (Chapter 9)

This chapter assists the retrofit contractor with an inventory assessment of their skill set and offers ideas to identify opportunities by customer type and motivation. Chapter 9 discusses a simple strategy for the retrofit contractor:

- Get customer to agree to the Building Walkthrough.
- Use the Building Walkthrough to Sell an Energy Audit.
- Use the Energy Audit to obtain retrofit work.



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CHAPTER 2

COMMISSIONING

2.1 INTRODUCTION

2.1.1 Commissioning – Contractor Benefits

Commissioning benefits to all parties are maximized when HVAC contractors are an integral part of the commissioning process. Commissioning is a team effort, and the HVAC contractors are a vital part of the team. It is the HVAC contractor who is directly responsible for the quality of workmanship and care when all the systems come together in construction. A contractor who works with the process will reap a variety of hard and soft benefits. In particular, the benefits of commissioning to contractors can include:

- Improved construction planning, collision avoidance, and coordination;
- Few to no outstanding deficiencies at substantial completion;
- Quicker project completion;
- Better documentation of equipment startup, which aids warranty administration;
- More satisfied clients and owners after completion;
- Reduced callbacks, and
- Therefore, lower operating, and maintenance service costs.

2.1.2 Commissioning – Benefits to Owners

The application of the commissioning process within an existing building can provide many benefits. Commissioning existing buildings can identify causes of operating problems, the sources of occupant complaints, or identify avoidable costs. It can then provide the means to develop a roadmap to plan, carry out, and functionally test corrective measures. Problems that can be identified and corrected through commissioning existing buildings include:

- HVAC systems functioning incorrectly,
- HVAC systems operating inefficiently,
- HVAC systems zoning and layout not matching current occupancy or usage patterns,
- Comfort needs of occupants not being met,

- Indoor air quality problems,
- Excessive and persistent occupant complaints,
- Increased maintenance costs due to unusually high equipment failures, and
- Improper interactions between various systems.

A prospective owner may also be interested in retaining the services of a commissioning authority for HVAC system problem identification. As part of a building energy survey, the structured and organized approach inherent in the survey and analysis phases of commissioning in an existing building can produce valuable insight into the condition and capabilities of the HVAC and other mechanical systems in the building.

2.1.3 Documentation and Drawings

In commissioning a new construction project, the relevant documents, shop drawings, balancing reports, and other information are generally available or will be at the appropriate time during the process. However, in existing buildings, this is unlikely to be the case.

For a building that was previously commissioned, there should be records including drawings, balancing reports, and commissioning reports. A previously commissioned building can be re-commissioned. The term re-commissioning is often used in other documents to mean applying the commissioning process to a previously commissioned building. The previous commissioning process should provide the framework and the first step is confirming that the owner's requirements for the building have not changed or understanding and documenting how they have changed.

For an existing building that was never commissioned there will likely be a lack of documentation and the likelihood that the owner is unfamiliar with the process. In many cases, a major task of commissioning an existing building is to gather the necessary data about the building and the existing mechanical system.

Once the data are available, the planning and execution of commissioning an existing building are very similar to the commissioning process previously described. The level of commissioning is contingent upon the owner's goals and expectations regarding the detail and outcome of the process. The major differences are that the building is already complete, there are not usually other trades on the site, and the building



may be occupied. These factors must be accommodated in the planning process.

2.2 PROCESS OVERVIEW

The commissioning process for existing buildings has six distinct phases:

- Preliminary investigation,
- Survey and documentation,
- Analysis,
- Design and installation of modifications,
- Actual commissioning process tests, and
- Documentation and Training

The commissioning agent may be initially retained to conduct the preliminary investigation.

NOTE: Commissioning definition—Process versus Technical Commissioning (Cx). A simple definition is that “Process Cx” involves a desk type Cx agent generating and then collating paper work with individual contractors doing the majority of the physical inspections and testing. “Technical Cx” is where the Cx agent develops the paperwork and then performs the majority of the actual inspections and functional testing.

2.2.1 Preliminary Investigation

The preliminary investigation phase is required to determine the availability of existing documentation and to estimate the level of effort required to:

- Confirm the accuracy of existing documentation,
- Carry out surveys, re-measurements of air and water flows, and other work needed to produce accurate documentation where none presently exists,
- Calculate space heating and cooling loads, outdoor air requirements, and any other relevant performance criteria,
- Identify, in general terms, any needed physical modifications to meet current occupancy and usage requirements, and

- Plan and carry out the necessary functional performance tests.

The information gathered during the preliminary investigation enables the commissioning agent to produce a commissioning proposal for the owner of the existing building. This proposal should contain a summary of the necessary work required for both the survey and documentation phase and the commissioning test phase, with estimates of fees required for each. At this stage, it is unlikely that any required modifications are defined sufficiently to permit the preparation of detailed cost estimates.

If the survey and documentation phase results in the definition of modifications necessary to correct mechanical system problems, then the costs of carrying these out and the decision of whether or not to proceed are made by the owner on the basis of this and other information.

The commissioning proposal for an existing building should break the work down into systems, floors, or other categories to the greatest extent practical. When this is done, it requires the commissioning agent to look at specifics, even at this stage of the project, and it gives the owner confidence that the commissioning agent has carried out the preliminary work in sufficient detail to produce a workable, beneficial retrofit plan.

If the owner agrees to the commissioning proposal, or the owner and commissioning agent agree on a revised scope of work, then the project proceeds to the survey and documentation, modifications (if required and agreed to by owner), and commissioning test phases.

2.2.2 Survey and Documentation Phase

The survey and documentation phase of a commissioning project for an existing building involves:

- Inspections and measurements to confirm the accuracy of existing documentation,
- Inspections and measurements necessary to produce new documentation where none presently exists, or where the existing documents prove to be inaccurate, and
- Preparation of any required new or revised documentation.

Depending on the quantity and accuracy of existing documentation, the level of effort for this phase can vary significantly.

2.2.3 Modifications Phase

The survey and documentation phase results in a complete set of project documentation sufficient to proceed with the commissioning process. However, it may also result in the identification of mismatches between present building use requirements and the existing mechanical systems. In some cases, these mismatches can be resolved by flow and controls adjustments and minor zoning modifications. In other cases, more significant modifications involving design and construction work are required. In the latter case, the owner has to make a decision whether to proceed with the required modifications and, in some cases, what the extent of those modifications will be.

2.2.4 Commissioning Tests Phase

Commissioning tests are comparable to the functional performance and verification. A commissioning plan should be prepared, complete with checklists.

2.3 PRELIMINARY INVESTIGATION

2.3.1 Existing Documentation

The commissioning agent's first task in commissioning an existing building is to obtain and review all existing documentation pertaining to the HVAC systems and any related systems included in the current commissioning scope of work. This documentation should include:

- **Installation Documents.** These include as-built drawings, specifications, and operations and maintenance manuals. Design heating and cooling load calculations and data should be part of this documentation.
- **Operational Documentation.** This includes test and balance reports (including outdoor airflow rates), commissioning reports (if commissioning was carried out on the building previously), energy consumption and cost data, and all records pertaining to control settings and operation. In addition, available records of occupant complaints and other data that could point to systems or operational problems are useful.
- **Service and Maintenance Records.** These records include information on a preventive maintenance program or service contract scope of work, if either is in place. In addition, all inspection reports and other service

and maintenance records should be available for review. This applies whether the work was done by the owner's staff, by service contractors, or by a combination of the two. Reports regarding refrigerant leaks or the addition of refrigerant need special attention as this may be subject to Federal regulatory requirements.

If complete installation and operational documentation is available, it is necessary to estimate the time and cost required to confirm its accuracy. If complete documentation is unavailable, then steps need to be taken to obtain the missing information.

2.4 SURVEY AND DOCUMENTATION PHASE

2.4.1 Confirming Existing Documentation

It is fortunate when complete installation and operational documentation is available. However, this existing documentation may not be up to date. Therefore, the commissioning agent's next step is to carry out surveys of the building to gauge the accuracy of the existing documentation. The extent of these surveys is a matter of judgment for the commissioning agent and agreement with the owner, because survey work can be time consuming and costly. Nevertheless, accurate data on existing conditions is critical to the success of any commissioning work, so the survey scope of work must be sufficient to confirm accuracy and, if necessary, to update existing documentation to reflect current conditions.

2.4.2 Creating Required Documentation

When installation and operational documentation does not exist, the commissioning agent must undertake survey activities to obtain data from which the required documentation can be prepared, and then prepare the documentation. The commissioning agent must determine the scope of work involved and agree with the owner on the scope before proceeding.

2.4.3 Surveys to Confirm Existing Documentation

When the survey work described in this section confirms the information on the existing documentation, some permanent, dated record of this confirmation is necessary. Then, any future commissioning will have a record of when the specific documentation's accuracy was last confirmed.



Where the survey work shows the existing documentation to be inaccurate, it must be revised, or in extreme cases new, accurate documentation must be produced.

2.4.3.1 Drawings

The commissioning agent should take existing drawings on site, visually observe present field conditions, and compare them to the existing drawings. The initial survey should focus on major items only, such as:

- Central heating and cooling equipment and its primary thermal distribution systems,
- The building envelope (important in evaluating building heating/cooling loads),
- Major air handling equipment and primary air distribution ducting.

The commissioning agent then carries out checks on whether heating, cooling, or terminal equipment and the zoning shown on the drawings still reflects actual field conditions. Important survey items are:

- Partitioning, changes indicate occupancy adjustments and a probable requirement for corresponding zoning adjustments,
- Zone terminal equipment and the specific spaces served,
- Heating or cooling equipment and the specific spaces served, and
- Location of thermostats, humidistats, and DDC sensors.

2.4.3.2 Equipment Data

Equipment data is closely linked with building surveys to confirm drawing accuracy. When doing these surveys, equipment must be examined and compared to that shown on the drawings, scheduled either on the drawings or in the specifications, or identified in the operations and maintenance manuals. Data can be taken from the equipment in the field and compared later to the existing documentation. Alternatively, the existing documentation can be carried into the field and used in direct comparison. In either case, data on the existing equipment must be recorded accurately as the survey proceeds.

2.4.3.3 Test and Balance Reports

If the existing test and balance (TAB) reports are more than 5 years old, it is unlikely they reflect current conditions in many areas of the building, particularly if any renovations or space reconfigurations have been done. A complete re-measurement of air and water flows is recommended.

Even if the existing TAB reports are less than 5 years old, they may still not reflect the current status of the building. Some flows, pressures, temperatures, etc., will need to be spot checked against those shown on the existing reports. Areas with occupant complaints should be checked first. The commissioning agent does these measurements or retains a qualified TAB contractor to do so, using the procedures outlined in the *SMACNA HVAC SYSTEMS TESTING, ADJUSTING AND BALANCING* manual. The survey data, and whether it confirms the existing TAB reports, must be recorded accurately.

2.4.3.4 Space Heating and Cooling Loads

When there is any evidence of persistent occupant complaints of “too hot”, “too cold”, “stuffy,” or other similar comfort problems, a “thermal zones” analysis should be carried out by or under the direction of the commissioning agent. This analysis involves two steps. First, the present heating and cooling loads must be calculated and compared to the installed capacity as shown on the existing documentation and as confirmed by survey. Data on the building envelope, lighting, occupancy, occupant, or process equipment in the space, the impact of the HVAC system on loads, and any other contributor to space heating or cooling loads must be considered. The second step is to evaluate whether the thermal zoning of the existing systems meet the design intent.

In particular, each zone should serve:

- Only perimeter spaces or interior spaces, but not both,
- Perimeter space, either at a corner or along only one exposure, or
- Only spaces of similar occupancy and load profiles.

If the actual loads are greater than installed zone capacity or the thermal zoning is not according to accepted criteria, then modifications are necessary.

2.4.3.5 Indoor Air Quality (IAQ) and Outdoor Air Ventilation

Indoor air quality (IAQ) and adequate outdoor air ventilation are both critical concerns for many owners and are key factors for occupant comfort.

If any IAQ concerns have been raised, a detailed evaluation is even more important. The present occupancy should be confirmed, contaminant sources (if any) identified, control of contaminants evaluated, and the required outdoor air ventilation amounts determined from applicable codes and regulations. In some locations, there are operational requirements for ventilation systems that must be followed. In other cases the outdoor airflow rates can be determined by the original design calculations, if the use of the building is unchanged, or by the current version of ANSI/ASHRAE 62.1. That amount of ventilation must be compared to the minimum outdoor air ventilation quantity shown on the existing drawings or other documentation and the actual ventilation rates must be confirmed by TAB measurements. If actual outdoor air requirements are greater than those being provided, then either control adjustments or physical modifications to provide adequate outdoor air should be considered.

IAQ investigations often require specialized knowledge. If the surveys indicate the possibility of significant IAQ problems, the commissioning agent should retain a qualified specialist for this aspect of the work such as a certified industrial hygienist experienced in IAQ investigations.

2.4.4 Surveys to Produce New or Revised Documentation

The procedures described in this section apply when there is no existing documentation or when existing documentation is no longer accurate. In either case, the information must be produced or updated.

The survey activities described in other sections also apply here; however, there is the additional requirement to produce new or revised documentation.

2.4.4.1 Drawings

Field survey data must be collected in sufficient detail to permit the preparation of as-built drawings when none exists. If existing drawings require revision, the survey data must provide enough data to complete the revisions and confirm the accuracy of material drawings not requiring revision.

In many cases, all the necessary data exists but they are on uncoordinated, original drawings and several sets of revision drawings. In such cases, it may be advisable to create a single, new set of as-built drawings incorporating all revisions to date as confirmed by a site survey. The new as-built drawings will be more usable than previous drawings.

2.4.4.2 Equipment Data

Missing equipment data may be difficult to replace. The starting point should be to prepare or update a complete schedule of equipment with as much information as possible about manufacturer, model number, serial number, capacity, flows, and other attributes. This information can come from nameplate data on the equipment, or existing schedules located on drawings or in specifications, TAB reports, or other sources. Missing information may be obtainable directly from the equipment manufacturers.

With rapidly advancing technology, equipment inventory documentation in a computer database should be considered, especially for larger projects. Consider using bar codes and a bar code scanner to mark equipment for easy retrieval of equipment data and include a report of the service history of each piece of equipment.

2.4.4.3 Test and Balance Reports

If there are no TAB reports available, the commissioning process needs to include a complete measurement of air and water flows, pressures, temperatures, etc. The commissioning agent carries this out directly; using the procedures outlined in the SMACNA *HVAC SYSTEMS TESTING, ADJUSTING AND BALANCING* manual, or retains a separate TAB agent to do so. This would produce new TAB reports showing current operating conditions.

If TAB reports do exist, but spot checks show they are inaccurate, then re-measurement of those areas showing inaccuracies is required. Updated reports correctly document current operating conditions.

2.4.4.4 Space Heating and Cooling Loads

Particularly in areas with persistent temperature complaints, actual space heating and cooling loads should be calculated. These loads must be compared to present delivered thermal capacities.

2.4.4.5 Outdoor Air Ventilation

Outdoor air ventilation requirements should be determined from applicable codes and regulations.



These requirements must be compared to present outside airflows. In some cases “old” codes set the minimum requirements and in other cases—such as where major renovation is underway—new code requirements must be met. Regardless of code minimums, common sense must be used to increase outdoor air supplies where situations warrant or occupants demand higher fresh air volumes.

In many dense urban areas outdoor air pollution levels may have increased since the building was originally designed and constructed. Consideration must be given to remedies to deal with polluted outside air while meeting code-mandated minimum airflows.

2.5 ANALYSIS

The commissioning agent must analyze the results of the survey and documentation phase of the commissioning process. From this analysis, a report should be prepared for the owner. This report contains a recommended action plan for:

- Replacement of equipment or controls nearing, or past, its useful service life. Often, when equipment is old, it has poor reliability, service and maintenance costs are high, and energy efficiency is lower than for new equipment. Replacement must be justified, but frequently the energy and maintenance savings and performance improvements are major benefits.
- Modifications required so the HVAC systems meet code requirements with respect to heating or cooling capacities, thermal zoning, total airflow rates, outdoor air ventilation rates, exhaust air requirements, or any other factor included in the owner’s performance criteria for the installation.
- Energy savings opportunities that may have been revealed by the commissioning survey and analysis work.
- Retrofit and upgrade of control systems. Often there are significant savings available from the improved control, monitoring, trending, and alarm reporting capabilities of modern, computerized Building Automation Systems (BAS) installations.
- Commissioning test plan.

The report must be definitive. If HVAC system modifications are required, the report should provide a de-

tailed list. If it is part of the commissioning agent’s scope of work, preliminary design information including schematic diagrams or plans, where physical changes and installations are involved should be provided. This will require the commissioning agent to have or obtain the necessary HVAC system design expertise.

When the owner gives approval, the commissioning process can proceed to the next phases.

2.6 MODIFICATIONS

Modifications will be required when the demands of the current use or occupancy of the building, or spaces within it, are not capable of being met by the HVAC systems as currently installed, adjusted, or operated. For example, space changes by tenants may require HVAC system zoning changes.

Modifications may be as simple as controls adjustments or adjustments to air and water flow volumes.

Finally, if the shortcomings are significant, the requirement may be for major renovations, even complete system replacement under extreme circumstances.

As the details of required modifications become known as a result of the survey, documentation, and analysis work, its cost is estimated as a part of that work. It is then up to the owner to decide how much of this work to authorize. If possible, the approved modifications should be carried out before the final commissioning tests are done.

2.7 COMMISSIONING TESTS

2.7.1 Commissioning Plan

As with any commissioning activity, a written commissioning plan is essential if the process is going to be effective and efficient.

If there are no systems modifications, it may not be necessary to have a systems readiness section. That work was covered in the survey phase. In addition, if the commissioning agent is also acting as the owner’s commissioning authority, the separate functional performance verification stage may be unnecessary.

If there are systems modifications, checklists for pre-start checks and start up procedures are important. The reason is that planning and scheduling are particularly important on most commissioning projects in an existing building. This is because the building is likely to

be occupied for the duration of the process; therefore, careful scheduling of the work, often after normal business hours, is essential to minimize occupant disruption. It is important to ensure work is ready when scheduled to avoid delays and disruptions. Detailed planning and checklists, plus an effort to use them effectively, can be very beneficial to a carefully executed commissioning plan that causes minimal disruption to the building's ongoing activities

2.8 DOCUMENTATION AND TRAINING

2.8.1 Operations and Maintenance Manuals

For the benefits of the commissioning effort to be fully realized, up-to-date operations and maintenance manuals are essential. Even if no modifications are carried out, revised manuals may be required. If modifications are undertaken, the new manuals must include complete data concerning those modifications.

A complete and detailed sequence of controls must be a part of these manuals. The sequence of controls needs to cover operator procedures in categories such as:

- System start up and shut down,
- Procedures related to abnormal conditions, including alarm response procedures,
- Procedures related to emergency conditions,

- Recommended system monitoring and recordkeeping and how to analyze this data to evaluate ongoing equipment and system performance, and
- Any seasonal adjustments required or recommended.

2.8.2 Training of Operations Personnel

Operations personnel must understand how to keep the systems operating as intended; therefore, training is another essential part of the commissioning process. Often the training has to be as comprehensive as that provided for a new building. On the one hand, there may have been considerable operator turnover, and the present personnel may not have had any training specific to the building's operation. Also, the operators have been operating the systems (effectively or ineffectively) and may well have many questions arising from their own experiences.

Training must include a review of all the documentation produced during the commissioning process. The operators need instruction in what the documentation contains, how to find what they need, how to use it to their best advantage during their work, and, most important of all, how to go about keeping it up to date. It is often useful to record the training sessions to be used as a reference for current personnel and new operators.

Keeping up to date includes such issues as periodic rebalancing, appropriate service and maintenance procedures, and continuous commissioning of the facility, or parts of it, in order to confirm future conditions.



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CHAPTER 3

ELECTRICAL

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3.1 INTRODUCTION

This chapter covers retrofit opportunities that involve replacing and installing electrical devices with the purpose of improving power consumption efficiency. The three areas that have the most potential for return on investment are motors, lighting, and utility cost management both energy and demand reduction.

The required test equipment to perform an electrical retrofit analysis and survey are as follows:

- Multimeter for volt/amp/resistance measurement.
- Power factor (PF) measurement meter.
- Power line harmonics measurement meter.
- Camera to document equipment and areas of interest.
- Light meter to quantify current lighting levels.
- Dataloggers to measure and record energy use of loads.
- Optional – Thermographic camera to identify electrical “hot spots”.

3.2 ELECTRICAL REVIEW

3.2.1 Power Factor

A low *power factor* increases the losses in electrical distribution and utilization equipment such as wiring, motors, and transformers. If the service line to a building has a low power factor, the result is lower distribution capacity, higher current flows, higher voltage drops, and higher electric bills. The power factor is the ratio of actual power (kW) to apparent power (kVA); it also may be expressed as the cosine of the phase angle between the impressed voltage and the current, *see* Figure 3-1. Electric utilities must supply enough current to supply the total apparent power, kVA, so they often charge customers a penalty for low power factor. There are hand-held power meters that can measure power factor directly.

Equation 3-1

Power Factor (PF) = COSQ =

$$\frac{\text{Real Power}}{\text{Apparent Power}} = \frac{kW}{KVA}$$

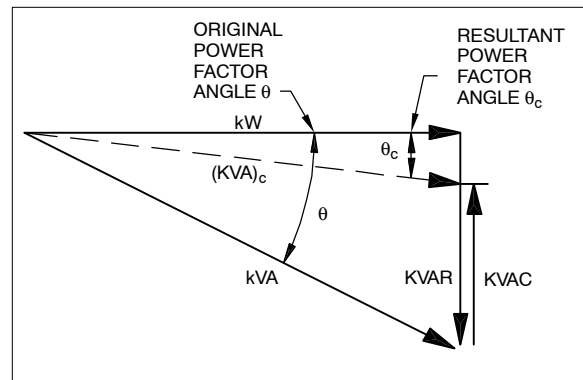


FIGURE 3-1 POWER FACTOR RELATIONSHIPS

When the power factor is near 1.0, the power factor losses are near zero. When the power factor falls below 0.95, utilities often institute a penalty charge for low power factor.

Of interest to the retrofit contractor are power factor correction strategies. Since utilities often impose a low power factor penalty, the customer benefits from power factor correction not only in equipment efficiency improvements but on the utility bill as well. Also, increasing power factor will result in achieving motor rated efficiencies and starting torques.

3.2.1.1 Power Factor Correction

Low power factors—below 0.80 to 0.90—result in reduced voltages, which causes increased current draw, lower motor efficiencies, lower motor starting torques, reduces lighting outputs, and reduces heating rates from resistance heating elements. Common causes of low power factor are induction motors, inductive loads such as transformers and magnetic ballasts, and nonlinear loads such as variable frequency drives (VFD). Induction motors are often the cause of low power factor because they are often oversized. Induction motors should be operated within 65 to 100 percent of full-rated load.

There are a number of devices available for power factor correction. Three of the common devices are capacitors, synchronous motors, and synchronous condensers. Synchronous condensers are the most expensive and are rarely a practical solution for building services applications.

Capacitor correction is relatively inexpensive both in material and installation costs. Capacitors can be installed at any point in the electrical system, and will improve the power factor between the point of application and the *power source*. However, the power factor

between the utilization equipment and the capacitor will remain unchanged. Capacitors are usually added at each piece of offending equipment, ahead of groups of small motors, ahead of motor control center distribution panels, or at main services. Refer to NEC Article 460 for installation requirements. The advantages and disadvantages of each type of installation are listed in Table 3-1.

Where loads contributing to a low power factor are relatively constant, and system load capabilities are not a factor, correcting at the main service may provide a capital cost advantage. When the low power factor is derived from a few selected pieces of equipment, individual equipment correction is likely to be the more cost effective path. Most capacitors used for power factor correction have built-in fusing. If not, fusing must be provided.

3.2.2 Line-Side Harmonics

Harmonic-generating loads are nonlinear loads that distort the alternating current waveform. Harmonic-generating loads draw a non-sinusoidal current from a sinusoidal voltage and they contribute to low power quality. Often, but not always, these are devices that convert AC to DC voltage. The most common

devices that create harmonics are variable frequency drives (VFDs), variable speed devices such as split capacitor rectifiers (SCRs), and uninterruptible power supplies (UPSs) such as used to keep power to computers during primary power loss. Some of the problems that result from harmonics are:

- Blown fuses
- Overheated transformers
- Tripped circuit breakers
- Failed power factor correction capacitors
- Reduced power factor
- Voltage distortion

3.2.3 Harmonics Correction

The current total harmonic distortion (THD) is ideally 0 percent, which represents a perfect sinusoidal waveform, but this is virtually impossible to maintain. Refer to IEEE Standard 519, *IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems* for recommended maximum THD levels.

Individual Equipment	Individual Equipment	Main Service Equipment
Advantages	Advantages	Advantages
Increased load capabilities of the buildings' distribution system.	Increased load capabilities of the service.	Lower material and equipment capital and installation costs.
Can be switched with equipment thus no additional switching is required.	Reduced material costs relative to individual load correction.	
Better voltage regulation because capacitor follows load.	Reduced installation costs relative to individual load correction.	
Capacitor sizing is simplified.		
Capacitors are coupled with equipment thus would move with equipment if rearrangements are instituted.		
Disadvantages	Disadvantages	Disadvantages
Small capacitors cost more per kVAR than larger units (economic break point for individual correction is generally at 10 hp).	Switching means may be required to control amount of capacitance used when serving multiple loads from a single supply point.	Switching means may be required to control amount of capacitance applied.
		Does not improve the load capabilities of the building's internal distribution system.

Table 3–1 Capacitor Correction For Power Factor



To reduce harmonics, use six-pulse pulse width modulated (PWM) variable speed drives (VSDs) that use a series reactor in the input AC line or internal DC bus. Active harmonic filtration equipment can reduce harmonic distortion to as low as 3 percent. There are also harmonic cancelling transformers that are constructed to cancel the higher orders of the line frequency.

3.3 UTILITY CHARGES

Saving energy does not always equal saving money. This is due to the various rate structures used by utility companies. Knowing when to reduce electricity usage will result in maximizing energy savings. Retrofit contractors should match the retrofit technologies to the electrical energy rate schedule faced by the customer.

3.3.1 Demand Charge

Utility companies use *demand charges* to encourage customers to use energy uniformly throughout the day. This is done because the power supply capacity must supply the *peak load* requirements of all energy users. Demand charge is equal to a fixed dollar per kW times the amount of kW for the time period. The kW for the time period is often the highest power draw during any 15 or 30 minute interval. The demand charge is often 30 to 70 percent of a typical electric bill. The retrofit contractor should think in terms of retrofits that, at a minimum, use electrical power evenly throughout the day or consider retrofits that shift loads into the off-peak hours during the entire 24-hour period.

Two customers on the same commercial rate may use the same amount of energy during a one-hour period, but be charged differently due to the differences in demand. This is because one customer used the power over 60 minutes, while the other customer used the same power over a 15 minute period. Demand charges encourage customers to spread out the electricity needs more evenly.

3.3.2 Real-Time Pricing

Real-time pricing is when the customer is charged the current market rate for electricity as it is consumed. If a customer is subject to real-time pricing, then predicting energy savings becomes more difficult due to the unpredictable nature of market prices for electricity. The ability to quickly vary or drop loads can be used to reduce energy use during periods of high prices. This type of rate is generally applied to very large energy users or accounts that choose this type of electric rate structure.

3.3.3 Time-of-Day or Time-of-Use Charges

Utilities may have a higher kWh charge during the day versus the kWh charge during the evening and overnight. It is prudent for the electrical energy user to not only reduce the peak energy, but to shift the time that energy is used. Thermal energy storage (TES) is the best technology to benefit from this rate structure.

3.3.4 Block Rates

Rather than charge a flat cost per kWh used regardless of the amount of kWh consumed, utilities may use block rates which refer to tiered pricing. Block rates can be structured as increasing or declining blocks depending on whether the utility wants to encourage or discourage higher rates of usage. Refer to Table 3-2 where increasing and declining block pricing examples are shown. Note how the cost per kWh charged decreases in blocks of 6000 kWh for the declining block pricing.

Increasing Block Pricing	
0 to 6000 kWh	0.035 \$/kWh
6001 to 12000 kWh	0.039 \$/kWh
12001 to 18000 kWh	0.043 \$/kWh
Declining Block Pricing	
0 to 6000 kWh	0.045 \$/kWh
6001 to 12000 kWh	0.040 \$/kWh
12001 to 18000 kWh	0.036 \$/kWh

Table 3-2 Utility Block Pricing – Increasing versus Declining

3.3.5 Ratchet Charge

Some utilities assess a ratchet demand charge against all energy consumed and that ratchet is based on the highest demand that was incurred during the preceding year. If a customer has a ratchet charge, then demand-related cost savings will not start to materialize until the end of the current ratchet period which might be as much as 12 months. This will impact the economic analysis and proposals for energy-related cost savings in the near term but demand controls and the application of appropriate HVAC technologies can yield significant dollars savings and fast paybacks where these charges are in effect.

3.3.6 Character of Service

The utility may assess a character of service charge to the customer. This charge is based on the service



voltage supplied to the customer. Higher service voltages generally result in lower per unit energy charges.

3.3.7 Power Factor

When the power factor is below a utility-prescribed threshold, usually starting at about 0.95, utilities often add a penalty charge for low power factor. Although the methods of computing the charge vary, the magnitude is about the same. A poor power factor also reduces the capacity of the electrical supply service. For example, with a power factor of 0.80 percent, electrical service spare capacity is decreased by an additional 25 percent of the load, and transmission losses are increased by 56 percent when compared to a power factor of 1.0.

3.4 EQUIPMENT

Equipment such as air handlers, chillers, cooling towers, and other related HVAC equipment use motors extensively. The application of VFDs, high efficiency motors, or a combination of both can have a significant impact on the total energy used by this equipment and reduce peak demand. If the retrofit contractor also uses equipment staging and time-of-day energy usage strategies, further energy-related cost reductions are possible.

Since the greatest portion of an electric bill is determined from the total kWh used and the demand charge, the electrical retrofit analysis should consider both total electric consumption and peak-demand reduction. There are many opportunities to accomplish both but some are more cost effective than others. Identify retrofits that have a quick payback period. Building owners are more likely to move on retrofit proposals with a two-year or shorter payback period. SMACNA's *Energy Systems Analysis and Management* manual provides methodologies for calculating energy savings and payback periods.

3.4.1 Motors

Original building cooling and heating load calculation estimates are usually conservative. When building loads have been or are reduced through conservation measures, most motors on existing equipment will be oversized for the load they are serving. If the ratio of the motor loading to the motor's power rating is small, the power factor will be low and the motor will not operate efficiently.

3.4.1.1 Motor Efficiency

Motor efficiency is the mechanical power output divided by the electrical power input. Since there are inherent losses in a motor, the efficiency will always be less than 100 percent, meaning that it will take more power input than the output power that is produced to drive equipment. Motor efficiencies given by the manufacturer are based on the efficiency obtained at full-load. The motor efficiency will not vary much down to approximately 75 percent of full load.

There is no uniformly recognized motor efficiency terminology. One manufacturer will refer to motors as high-efficiency or premium-efficiency motors as if this represents some universal standard. This is not the case. One manufacturer's premium-efficiency motor may be equivalent to another manufacturer's high-efficiency model. Make comparisons based on the actual efficiency rating number, not what the motor is called. Also note that larger capacity motors inherently have higher efficiencies than their smaller counterparts, with 95 percent efficiencies being common.

3.4.1.2 Comprehensive Motor Survey

Make a comprehensive study of all motors in existing buildings to determine their performance and load factors. Gather and record the following information:

- The equipment served by the motor.
- The nameplate information for each motor, including: brand, model or type, horsepower, RPM, volts, phase(s), amps, frame, enclosure, power rating, speed or speeds, service factor, efficiency, etc.
- Measure and record the running current of each phase leg supplying power to the motor.
- Measure and record the voltage at the motor when measuring running current.
- Record drive/type/size including pulley sizes and drive type—V-belt, cog belt, direct, etc.

The motor service factor establishes the maximum acceptable overload without exceeding the motor's temperature rating. Utilize this information (if not on the nameplate, contact the manufacturer) when in the process of exchanging and interchanging the motors currently in use. For cycling equipment, select smaller motors rated slightly below maximum load requirements and allow some overloading to occur while remaining within the motor's service factor.

Match the phase and frequency of newly installed motors with the characteristics of the electrical distribution system. When motors cannot exactly match the system voltage, select the following:

- For motors loaded to 75 percent of their capacity, select motors rated at slightly more than system voltage.
- For motors loaded to more than 75 percent of their capacity, select motors which are rated slightly under the system voltage. Problems may arise if nameplate rating of motor selected is in excess of system voltage by more than 5 percent. Additionally, the difference can also increase due to potential utility brownouts in voltage cutbacks.

3.4.2 Variable Frequency Drives (VFD)

A variable frequency drive (VFD) is a device that controls the speed of an AC motor by converting a constant AC voltage and frequency to a variable voltage and frequency. A VFD allows an AC induction motor to operate at different speeds. This is useful in applications where loads are changing and are often running at part-load conditions. Common retrofitting applications for VFDs include air handlers, chiller pumps, and cooling towers. Opportunities for VFD applications can be determined from the documentation gathered during the comprehensive motor survey.

Although VFDs have several advantages and can result in significant energy cost savings, be sure to consult the VFD and motor manufacturers to insure a successful installation. A few guidelines to consider are:

- Do not exceed manufacturer's recommended maximum length of power cable between the VFD and AC motor.
- Do not operate VFD control below manufacturer's recommended cutoff speed, which may be 25 to 35 percent of maximum.
- Consider replacing an existing motor with an *inverter duty motor*, which is an AC motor that has heavy-duty windings and modifications to make it resistant to the spikes and modified sinusoidal waves inherent in the VFD-modified signal.
- Consult the manufacturer of VFD to obtain recommendations about possible negative effects to power factor and harmonics.

- When VFDs are added to existing motors add grounding rings around the motor shaft to avoid premature bearing failure.

3.4.3 Motor Replacement Strategy

A motor replacement strategy is a process of documenting the building's motor installations, evaluating the equipment's actual required motor power compared to the installed motor, and developing a written plan for motor upgrades and replacement.

If a motor is operating below 50 percent of full load, replace it with a smaller, higher efficiency motor that is sized to operate at closer to 100 percent of full-rated load. Motors that are not loaded to at least 60 percent of their potential are operating in an inefficient range and reduce the power factor of the entire electrical system.

If a motor is driving variable loads, consider the installation of a VFD. This will improve the power factor during light loading periods and reduce power consumption.

A written motor replacement strategy can be used by facility maintenance personnel to quickly replace motors that fail with the appropriate replacement motor and should be included in the final documentation materials.

3.5 LIGHTING

3.5.1 General

Lighting is one of the major uses of electrical energy and accounts for about one fourth of the national electrical energy budget, which amounts to over 37 billion dollars annually in the United States. In commercial buildings energy used for lighting accounts for about 30 percent of the total energy usage. However, lighting actually contributes a greater percentage of total energy use since the heat generated from lighting in buildings must be offset by the cooling as well and can account for as much as 60 percent of this load in existing buildings.

There are many opportunities in both new and existing buildings to reduce energy consumption by addressing lighting suggested in this section. For instance, windows can be used for day-lighting to reduce lighting electrical requirements. For this strategy to be effective, lights near windows must be turned off when daylight provides sufficient illumination. This can be done most effectively with automated devices that sense light levels and dim or turn off lights automatic-



ally. Task and work areas that are fixed and well-defined can use task lighting that operates at low power consumption levels. Where building usage has been established, programming of systems to light spaces to the levels they require can be made on a selective, as-needed basis. *Caution: Some areas—especially egress—have minimum allowable light levels that are addressed by code, OSHA, or similar regulatory requirements.*

The most effective opportunities for reducing energy consumption are those with minimal cost and modification to the existing lighting systems. Many of the opportunities and options for further reducing energy consumption also can be done at relatively low costs, such as adding switches, occupancy sensors and pilot lights, group re-lamping, and replacing defective ballasts with more efficient ones.

Consider strategies to:

- Utilize available daylight more effectively for illumination and automatically turn off or control electric light levels with sensors.
- Improve lighting system efficiency by increasing the light delivered to the task through more frequent fixture maintenance.
- Switch off lights at night and in unoccupied areas during the daytime. Occupancy sensors are one of the most effective strategies.
- Reduce the levels of illumination at selected task locations and lower them further between or beyond the task locations.
- Re-lamp with more efficient lighting technology.
- Modify the existing lighting fixtures and their location in the room to provide a greater amount and better quality of lighting.
- Reduce the losses in the power distribution system which serves the lighting system. As ballasts require replacing, use efficient, high-power factor types.

Be aware that advances in lighting technology have occurred frequently and in recent years. What may be thought to be the best available lighting technology

may actually be inefficient compared to the best currently available technology.

3.5.2 Lighting Levels

When designing or modifying lighting systems in buildings, information from ASHRAE, IESNA, and GSA can be used. These sources provide comprehensive viewpoints of lighting illuminance requirements as it impacts energy conservation.

Illuminance is measured in foot-candles (FC) or LUX. A foot-candle is one lumen of light density per square foot, one lux is one lumen per square meter.

Light level or illuminance is the amount of light measured at a plane. The work surface (plane) is where most tasks within the space are performed. Full outside daylight has an illuminance of 1000 FC (10,725 LUX). From a “rule of thumb” standpoint, general area lighting in the range of 50 to 70 foot-candles at the work surface is widely accepted by lighting designers for normal office tasks. Higher illuminance is required for tasks such as drafting.

Energy efficiency standards and codes limit lighting densities in Watts per unit area with 1.0 watt/ft² (W/0.929 m²) being a typical upper power density limit for offices. Codes are moving toward increasingly restrictive lighting power densities such that many existing older lights cannot comply with both the illuminance and power density requirements where a major renovations “pulls” the entire building under the new code’s energy efficiency requirements.

Interior surface finishes on walls and ceilings have a substantial affect on lighting levels. In colonial times, white lime was added to paint to increase surface reflectivity to assist with the low light levels from pre-electric sources. Today, paints are available with published light reflective values (LRV) that indicates how much light at paint reflects. LRV are important for the visual ergonomics of a room because they can assist the natural and artificial light propagation within the indoor environment.

Lighting power level reductions are very beneficial because every Watt saved using more efficient lights saves another Watt plus by reducing the cooling energy required to offset the interior lighting load.

Lamp type	Advantages	Disadvantages	Lumens per Watt	Life range (hours)
Inductive Fluorescent	energy efficient; warm color; instant on capability; dimming capability	expensive; not widely available	50 to 100	15,000 to 100,000
Compact fluorescent lamps (CFL)	energy efficient; easy replacement of incandescents	retrofit lamps cannot be dimmed	50 to 100	5000 to 20,000
T-12 fluorescent	energy efficient; inexpensive	Less efficient than linear fluorescents	50 to 100	10,000 to 20,000
Linear fluorescent (T-5, T-8)	more energy efficient than T-12 they replace	can be blinding if close to viewer	50 to 100	10,000 to 45,000
Metal halide high intensity discharge (HID)	Energy efficient; bright white light	Slow start; UV radiation; expensive	65 to 115	10,000 to 30,000
Incandescent	warm color; can be dimmed	short life; energy inefficient	10 to 20	750 to 2000
LED	long life; energy efficient	poor color; not dimmable, expensive	50 to 150	40,000 to 100,000

Table 3–3 Comparison of Lamp Types

3.5.3 Lamp Types

There are many types of lamps and it is critical to have an understanding the relative advantages and disadvantages, lamp life, and other factors important in the decision of replacement and retrofit. *See* Table 3-3 for a comparison of the various lamp types. Replace T-12 fluorescent fixtures with T-8 or T-5. As a general rule of thumb, use T-5 fixtures for applications above 20 feet and T-8 fixtures for below 20 feet, since the bright white light from T-5's can be blinding if they are too close to the occupants.

3.6 PEAK DEMAND POWER MANAGEMENT

A proper program of electrical system management and maintenance can help prevent excessive energy losses, reduced equipment life, and hazardous conditions associated with poorly maintained equipment. Although probably adequate when first designed and installed, existing systems may not now be able to carry the proper loads due to changes in layout and uses. Additions or shifts in motors may have affected working voltage of the system, thus affecting motor operation, lighting efficiencies, and conductor loading.

Low voltage conditions at motors cause high amperage draw which increases line losses. Overvoltage causes some motors to become less efficient. Under-

sized wire increases line loss. Loose connections and bad contacts—which can be readily found with thermographic devices—cause increased amperage draw and power loss as well as heating and arcing which are both inefficient and dangerous. Unbalanced voltages in three-phase motors can create inefficient motor operation. Power leaks to ground also can cause substantial loss of energy, arcing, and create unsafe conditions.

Outdoor switchgear energy losses can be increased by heat. Provide shading, but avoid obstructions which could diminish natural ventilation.

Water, dust, heat, cold, humidity, dryness, corrosive atmospheres, vibration and other conditions all affect the performance and usable life of electrical apparatus. For this reason, it is essential to regulate to as great a degree as possible the environment of the equipment and control rooms where the electrical apparatus is located. It is suggested that such rooms be kept dry and that appropriate ventilation be installed for enclosed rooms to prevent heat build-up. High humidity can increase contaminant build-up on electrical parts which can cause inefficiencies and, in some cases, total breakdowns.

Proper management of transformer operation and related factors can result in significant energy savings. The following guidelines should be considered:



- Shade exterior transformer banks from solar radiation to reduce heat build-up and resultant losses.
- Ventilate transformer banks to keep them as cool as possible.
- De-energize transformers whenever possible to stop stand-by losses.
- When installing new transformers, select those designed for a lower temperature rise but furnished with high temperature rise insulating materials.

3.6.1 Reducing Loads

Automatic timers with remote control switching should de-energize equipment which is not required at night and during weekends. It is natural to think first of large motors and loads only, but the power consumption of many small, inefficient motors in aggregate can exceed the same amount of connected horsepower of one large motor. Where electrical circuiting permits, control the operation of small, motor-driven equipment by a single timer, and re-circuit where possible when multiple circuits supply equipment.

In addition to motors, other loads such as resistance heating equipment, electric cooking equipment, meat preparation rooms in supermarkets and restaurants, electric signs, business machines, and mechanical and electrical equipment can be de-energized for a substantial portion of the week. Transformers without loads should be de-energized to save core standby losses.

3.6.2 Peak Loads

The major purpose of *load shedding* is to reduce the peak electrical loads to decrease electrical *demand charges*. Since many of the largest loads are deactivated for considerable periods of time, load shedding conserves energy in addition to reducing electrical equipment power and line losses. Where manual load shedding cannot be instituted because of cost and demand upon personnel, consider automatic load shedding.

First, tabulate all electrical loads. Schedule the periods when they must be in operation and the duration of time that they can be disconnected without impairing the safety or comfort of the occupants or affect the condition of the structure and equipment. Then, organize the load shedding program to shut down those

loads by a timing device when the hours that operations can be suspended are predictable so that large loads are not allowed to operate simultaneously. Peak loads which are not predictable in advance can be monitored, and equipment operation can be automatically programmed to respond to load conditions by de-energizing selected loads by priority, and reactivating when reduced demand permits. New loads are also precluded on a priority sequence.

Available automatic load limiting devices range in complexity from a simple thermal sensor which works much like a circuit breaker's thermal element and switches off a low-priority load when the building load reaches a preset point to a unit that senses total building current and provides for shedding and restoring loads. Automatic load shedding is also commonly accomplished with a Watt-hour meter combined with time switches and load controllers.

3.6.3 Demand Control Systems

To select a specific demand control system, it should be understood that each system comprises three essential elements: input, logic, and output.

3.6.3.1 Input

Input to most demand control systems is in the form of pulses from the utility's kilowatt-hour meter incorporating a demand meter attachment. Each time a certain number of kilowatt hours accumulate, a pulse is generated. At the end of each interval the meter gives off an end-of-interval or EOI pulse. The pulse tells the control device that the interval is over and that a new interval has begun.

3.6.3.2 Logic

Logic refers to the operating method by which an automated demand control device performs its function of measuring the energy being consumed in the facility and limiting demand by shedding loads identified on a priority basis.

Demand control equipment available today ranges from relatively inexpensive units to highly sophisticated, large-scale computer systems. Some systems are not automated at all and work by shutting down equipment or sounding an alarm whenever the maximum demand setting is exceeded. Although this type of unit is applicable for some installations, it does not lend itself to highly effective control. Desired maximum demand will be frequently overshoot because action usually can't be taken until it is too late. In most instances, an automated demand control is the only viable choice.

3.6.3.3 Output

The output function of automated demand control systems acts on logical decisions and provides the actual control. This is accomplished by activating relays, contactors, or motor starters which shed or restore loads. The sequence in which loads are shed can be programmed. It can be specified that a given load is the last shed and first restored, or first shed and last restored, and so on.

3.6.4 Plug Loads the Energy Vampire

Plug loads refer to the power loading from outlets into which electrical devices are plugged. When many existing buildings were originally built cell phone chargers, computers and monitors, and personal printers were not considered. This not only may result in plug loads that are significantly greater than the system is designed to handle it also adds to the peak demand load and increases the load that must be offset by the HVAC system during cooling.

In spite of the fact that energy conservation has been incorporated into building codes with increasing effort and stringency for several decades, energy use in commercial office buildings per square foot has actually been increasing. Much of the blame for that increase in energy is attributed to the growth in plug loads. Most of that load growth has been fueled by desktop computers and the associated periphery.

While it is unlikely that computers will be exchanged solely to reduce energy use there are ways to address or at least offset the energy use issue.

In a many existing offices overhead lighting was installed primarily to light desktops. Now, more light is provided than is truly required, especially where much of the work is done on computers. Either the total count of overhead lamps can be reduced by simply removing bulbs and tubes or replaced with more efficient lights AND fewer bulbs. Or, task lights can be placed on desktops and overhead lights simply not be turned on—of course, this increases plug load so these choices may be driven by how much load is being carried by receptacles. Where receptacles wiring is overloaded and already creating nuisance tripping, task lights would not be the appropriate solution and could actually aggravate the problem.

From a long term planning standpoint, offices that use desktop computers could transition to laptops when equipment is replaced since laptops use less energy than desktops. Where CRT monitors are being used, they should be replaced with LCD screens. Instead of personal printers, consider centrally-located printers that serve many users.

The United States Energy Environmental Agency manages a program called Energy Star where manufacturers voluntarily test and rate certain energy consuming products. The yellow labels on refrigerators are one of the most well know examples of this program. Energy Star ratings are also applied to computers, printers, scanners and a host of other office equipment. Building owners need to at least be aware of energy use when purchase decisions are being made about office equipment or appliances such as those used in employee kitchens.

Ultimately, plug loads are driven by occupants and their behavior. Reducing plug loads in the short term is often as much consumer education issue as it is a technical issue. But there are certain loads that can immediately be removed—portable electric heaters. While there may be some rational for the use of portable heaters in the winter, there is absolutely no logic in having one plugged in when the cooling system is operating.

3.7 REFERENCES

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CHAPTER 4

BUILDING ENVELOPE

