Optimization of HVAC Control Strategies
By Building Management Systems
Case Study: Özdilek Shopping Center

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ABSTRACT

HVAC systems in buildings must be complemented with a good control scheme to maintain comfort under any load conditions. Efficient HVAC control is often the most cost-effective option to improve the energy efficiency of a building. However, HVAC processes are nonlinear, and characteristics change on a seasonal basis so the effect of changing the control strategy is usually difficult to predict.

Aim of this thesis is to reduce energy consumptions by defining new HVAC control strategies and tuning control loops in Ozdilek Shopping Center “OSC”. To investigate the potential for energy savings and to redefine control scenarios, an energy audit was carried out in OSC. According to these studies new strategies are implemented by the help of existing building management system “BMS” without making any investment. Performance indices were calculated and compared with the accepted standards. Then normalized performance indices are calculated to reach out a better understanding of the buildings’ efficiency.

ÖZ

Binalarda her türlü iklim koşulunda ısıl konforun sağlanması için ısıtma havalandırma ve iklimlendirme “HVAC” sistemlerinin iyi kontrol edilmesi gerekmektedir. Etkin bir HVAC kontrolü binalarda enerji tasarrufunun en iyi yoludur. Ancak HVAC sistemleri yapısı gereği lineer olmadıkları ve sezonlara göre karakteristikleri değiştikleri için HVAC kontrol stratejilerini ve kontrol parametrelerini belirlemek çoğu zaman oldukça zordur.

Bu tezin amacı Özdilek Alışveriş Merkezinde yapılan deneysel çalışmalar yardımıyla HVAC kontrol stratejilerini belirlemek ve parametreleri yeniden ayarlayarak sistemin konfor şartlarını bozmadan en düşük enerji ile çalıştırılmasıdır. Enerji tasarrufu potansiyelini belirleyebilmek ve kontrol stratejilerini en uygun hale getirmek için enerji bilançosu çalışması yapılmıştır. Bu çalışma sonunda binanın performans değerlendirmesi yapılmış ve kabul görmüş standartlarla karşılaştırılmıştır. Bu çalışmaların ışığında yeni kontrol stratejileri mevcut bina yönetim sistemi “BYS” yardımıyla uygulanmıştır.

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INTRODUCTION

1.1 General

For human beings, energy as work and heat has great importance for the continuation of life. Energy is the key to industrial development leading to the economic and social well-being of the world population. The growth of the world population, coupled with rising material standard of living, has escalated energy usage since the turn of this century [1].

Modern buildings and their HVAC systems are required to be more energy efficient while adhering to an ever-increasing demand for better indoor air quality and performance. Economical considerations and environmental issues also need to be taken into account.

Maintaining high standards of indoor comfort is an economically sound goal. Research shows that indoor comfort and productivity can be linked [2]. These studies indicate that the economic gain with a small increase in productivity outweighs energy savings obtained by reducing the indoor comfort levels. A balance between energy efficiency and indoor comfort must thus be obtained.

The goal of HVAC design in buildings is to provide comfort to the occupants. Because heating and cooling loads vary with the time of the day and of the year, an HVAC system must be complemented with a good control scheme to maintain comfort under any load conditions. Good control will also reduce energy use by keeping the process variables (temperature, pressure etc.) to their setpoint efficiently

Efficient HVAC control is often the most cost-effective option to improve the energy efficiency of a building. However, the effect of changing the control strategy (i.e. on indoor comfort and energy consumption) is usually difficult to predict. The success of implementing efficient energy management and control is coupled with understanding the performance of mechanical and control systems.

Control is essential feature of almost every engineering system and process. For many years, control was affected by analog means only. The advent of the microprocessor, however, made digital control possible, and cost reduction in their manufacture have led to their wide spread use in a variety of situations. Their adoption for the control of the building services systems has come to be known as energy management, and the terms “Energy Management And Control Systems” (EMCS) in North America and “Building Energy Management Systems” (BEMS) in Europe are used to describe installations of this nature [1].

BMSs centralize the monitoring, operations, and management of a building to achieve more efficient operations. BMSs have become an essential part of a modern building that contributes significant saving potential and function feasibility. However, the actual achievement of BMS relies on well-developed and commissioned BMS hardware and software, well-trained BMS users, and system designers of adequate knowledge and experience on BMS and dynamic performance of HVAC systems [3].

1.2 Present Study

The aim of the present study is to understand HVAC control principles and their applications, investigating the potential for energy savings and then reducing the energy consumptions by the help of BMS within a case study. Quite amount of money is invested to HVAC and its control systems which need to pay back in a short period. In HVAC automation sector, lack of knowledge brings long pay back times, high energy consumption and customer dissatisfaction.

In Chapter 1 the importance of efficient HVAC control and comfort in buildings are focused, then brief information is given about present study and literature survey. In Chapter 2 energy consumptions in buildings in Turkey is investigated. Then energy conservation activities and legislative studies in buildings are focused. Chapter 3 gives general idea on BMSs and its applications. Chapter 4 is theoretical study which aims to understand the automatic control principles in HVAC systems. Chapter 5 focuses the main idea of this thesis. This chapter explains the HVAC control principles and their applications. In Chapter 6 a case study which was carried out in OSC to investigate the potential for energy savings and to redefine HVAC control strategies are described. A methodology is developed for systematic approach to the case study. An energy audit is conducted and consequences are discussed. Performance Indices and Normalized Performance Indices of the building are determined and compared with accepted standards. An action plan is defined to initiate a site study. Within the site study current control scenarios are investigated then redefined strategies are implemented. Finally parameters are tuned to reduce fluctuations from set points. In Chapter 7 results of the case study are analyzed and discussed. In Chapter 8 conclusion is made with the overview of the entire study.

1.3 Literature Survey

Buildings form an important part of the modern lifestyle. Not surprisingly, it is also one of the largest industry sectors worldwide. Buildings, especially commercial buildings, are further one of the biggest consumers of energy. In developed countries, buildings account for between 30% and 40% of the energy consumed. Another alarming fact is that their energy consumption seems to be on the rise [4]. A report of the American Council for an Energy Efficient Economy showed that commercial buildings had the highest growth in energy consumption during the mid 1980s [5].

In general, most of the energy is used to maintain acceptable comfort levels within buildings. Of this, lighting and HVAC systems form the largest consumption items. Studies indicate that air-conditioning is responsible for between 10% and 60% of the total building energy consumption, depending on the building type [6,7].

Mathews et al. (2002) [8] conducted a case study on a Conference Center to increase its energy efficiency, by optimizing the HVAC system control, and in particular, the control of the heating plant. They emphasized that approximately 50% of the energy used by the commercial sector in South Africa is utilized for air-conditioning. This clearly shows that the HVAC system of a building has a large potential for energy saving. A cost-effective way to improve the energy efficiency of fan HVAC system, without compromising indoor comfort, is by implementing better control.

Zaheer-uddin et al. [9] explored the problem of computing optimal control strategies for time-scheduled operation of HVAC systems. The optimization problem that takes into consideration the building operation schedules consisting of night-setback, start-up, occupied modes and energy price discounts is formulated and solved for a given predicted weather profile. Results showing the optimal mass flow rates to the zones, air and water supply temperatures, energy input to the heat pump and the resulting zone temperatures are given.

Also some studies have been done on the optimization of supervisory control [10,11]**.** House et al. [10] investigated the problem of optimal control of the HVAC and building by using a systems approach.

Shengwei Wang et al. [3] developed dynamic and real-time simulation models to simulate the thermal, hydraulic, mechanical, environmental and energy performance of building a variable air volume VAV air-conditioning system and its BMS. A window-based user's interface is developed to simulate the man–machine interface of a BMS, through which users can monitor the on-line operation, tune the local control loops, and reset the supervisory control strategies.

Mathews et al. (2002) [12] developed a simulation tool, QUICK control to predict effect of changing control strategies (i.e. on indoor comfort and energy consumption) more easily. This tool was then used to investigate the energy savings potential in a Conference Center. The influences of fan scheduling, setpoint setback, economizer cycle, new setpoints, fan control, heating plant control, lighting control and various combinations thereof was investigated. The simulation models were firstly verified with measurements obtained from the existing system to confirm their accuracy for realistic control retrofit simulations. With the aid of the integrated simulation tool it was possible to predict savings of 744 MWh per year (32% building energy saving and 58% HVAC system energy saving) by implementing these control strategies. These control strategies can be implemented in the building with a direct payback period of less than 6 months.

Chapter 2

ENERGY CONSUMPTIONS AND ENERGY CONSERVATION ACTIVITIES IN BUILDINGS IN TURKEY

2.1 Overview

To be able to understand the importance of energy conservation in buildings, energy consumptions shall be compared by sectors. Figure 2.1 shows the energy consumptions (average values from year 1980 to 2001) ratios by sectors in Turkey. This graph proves how important to carry on energy conservation studies in buildings and in industry. 36% of the energy is consumed by residential and commercial buildings [13].

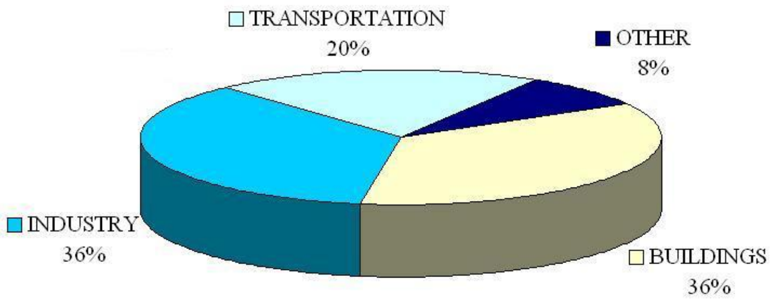


Figure 0.1. Energy consumption ratios by sectors in Turkey

Besides the technological improvement, Turkey has a great potential to make new and modern buildings either in residential or in commercial sector. This means energy consumption in buildings in Turkey is increasing. Figure 2.2 explains the fluctuations of energy consumption values in buildings between 1980 and 2001. Highest energy consumption was 19,830,000 [TEP] in the year of 2000. Energy consumption in buildings tends to increase by recent years. Energy consumption ratios in the buildings comparing with the other sectors are shown in Figure 2.3. The rate of energy consumption is share of energy used in buildings in total and this rate fluctuates between 32.8% and 46.5% between 1980 and 2001 in Turkey. In 1998 energy consumption ratio in buildings made a peak then decreased to its average value.

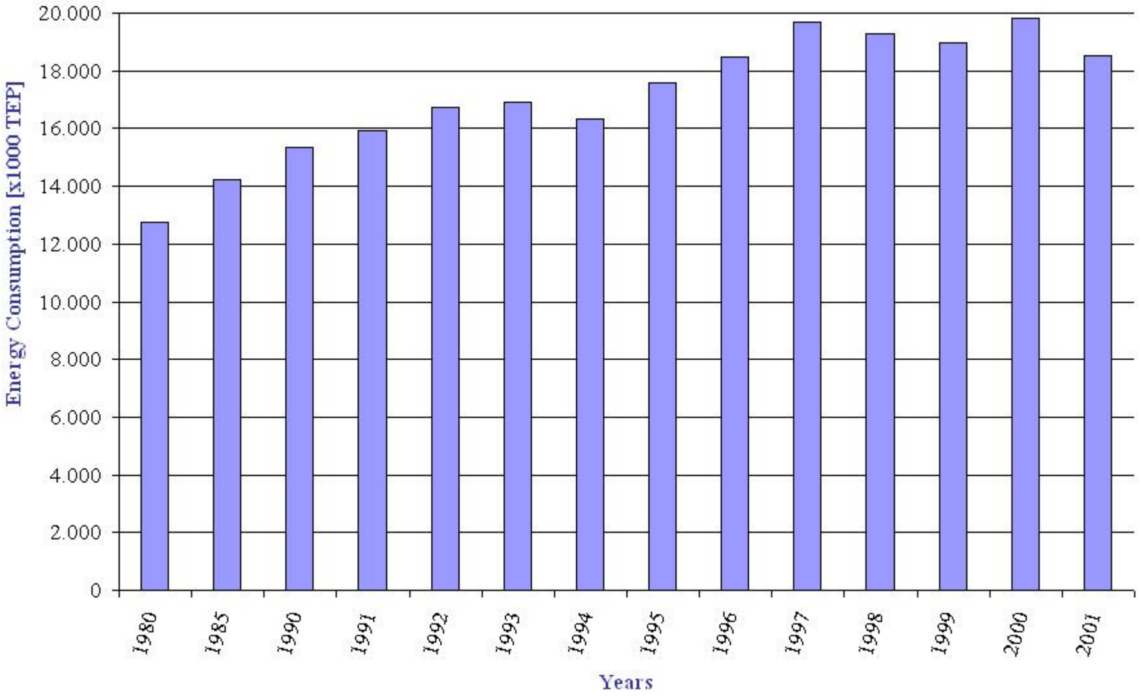


Figure 0.2. Energy consumption values in buildings in Turkey

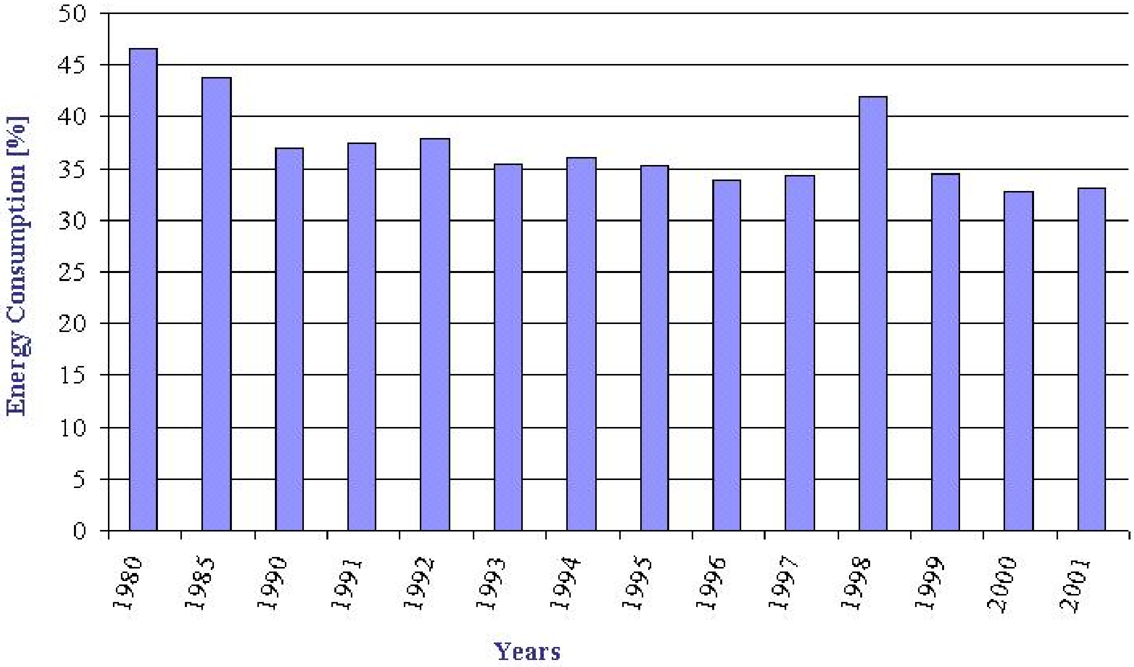


Figure 0.3. Energy consumption ratios in buildings in Turkey

2.2 Energy Conservation Activities In Buildings In Turkey

In Turkey, the energy conservation and efficiency studies have been mainly coordinated by The Ministry of Energy and Natural Resources (MENR). MENR have tried to establish the major objectives including energy efficiency and conservation in Turkey. There are two major energy conservation center called as the Energy Conservation Co-ordination Board (ECCB) and National Energy Conservation Center (NECC) of the Electrical Power Resources Survey and Development Administration (EIEI) which reports to MENR about studies on energy efficiency and renewable energy sources since 1981.

NECC has expenditures on studies, energy audits, publications and professional training. NECC benefits from international loans and expertise. ECCB is in charge of public campaigns on energy savings.

2.3 Legislative Studies

In the residential / commercial sector, more than 80% of the energy consumed is for heating. According to an EIE study carried out in 1997 based on questionnaires, energy use per unit building area could be reduced by nearly half by applying to all existing buildings the new *heat insulation standards* (TS 825) on building envelopes, issued in 1999 and effective since June 2000. In 1985, Turkey adopted mandatory standards for heat insulation in new buildings. However, heat losses in new buildings have been estimated at over 200 kWh/m^2/year which is a high level compared to average losses in Europe [14]. Revision of the standard for heat insulation in buildings was finalized in April 1998 and issued by the Turkish Standards Institute (TSE). This new insulation standard (TS-825) and supporting regulation introduced in June 2000 makes it mandatory to reduce heating requirements by 100-150 kWh/m^2/year. The existing building stock is increasing at an average rate of 5% annually. It is expected that a 50% improvement in energy efficiency in new buildings will be achieved by TS-825.

2.4 Governmental Buildings Energy Conservation Monitoring Programme

In accordance with the circular entitled measures to be taken by Governmental Organizations and Institutions in order to reduce their energy consumption issued by the Prime Minister, all governmental organizations have prepared annual reports on energy consumption in their buildings. These reports were sent to EIE/NECC by the ministry and evaluated by ECC. In 1999, information concerning 2,037 governmental buildings was evaluated [15]. According to the evaluation results, the energy consumption of these buildings was very high (more than 250 kWh/m^2/year); only 48% of them have double-glazing and 40% have roof insulation.

Another project named “Application of Energy Efficiency Studies in Buildings in Erzurum” has been initiated in co-operation with the German technical organization (GTZ), the Erzurum Municipality and EIE/NECC in November, 2002. The duration of this project will be three years. Its aim is to enable municipal authorities as well as users of public and private buildings to take measures designed to reduce the use of energy in buildings. Implementation of the project will be realized in Erzurum and studies related to standards, regulations and training will be carried out in Ankara.

2.5 Statistical Studies

At the end of 1997, in co-operation with the State Institute of Statistics (SIS), a statistical study for the analysis of energy consumption of residential buildings, which covered the whole country, was launched. In this project, the analysis of the energy consumption in terms of fuel and electricity, the insulation status, heating systems, and the structural properties of the residential buildings have been realized on the basis of geographical regions.

2.6 Energy Labeling / Standards

Under the co-ordination and supervision of EIE/NECC, and with the participation of representatives of the related manufacturers and public organizations, working groups have been set up on energy efficiency of household appliances, air conditioners and lightning.

The related analytic work reveals that new regulations are needed to increase energy efficiency for the before-mentioned equipment. In this context, studies to prepare energy efficiency labeling standards and regulations for electrical appliances have already been initiated by the TSE and the Ministry of Industry and Trade (MIT) within the framework of the Harmonization Programme for EU legislation. regulation on energy efficiency labeling for refrigerators was issued on March 2002. The other labeling regulations related to washing machines, dryers, dish washers and lamps have been prepared and should soon be published by the MIT. The energy efficiency regulation for outdoor (street) lighting is under review. In the 2000/2001 in-depth reviews of the energy policies of Turkey, the IEA stated: The Government of Turkey should enhance Turkey's participation in international co-operation programmes on energy efficiency, in particular on efficiency standards and labels for household appliances and motor vehicles and should consider establishing fiscal and economic incentives for conservation measures in all sectors.

Chapter 3

BUILDING MANAGEMENT SYSTEMS (BMSs)

3.1 Introduction

The objective of BMSs is to centralize and simplify the monitoring, operation, and management of a building or buildings. This is done to achieve more efficient building operation at reduced labor and energy costs and provide a safe and more comfortable working environment for building occupants. In the process of meeting these objectives, the BMS has evolved from simple supervisory control to totally integrated computerized control. Some of the advantages of BMSs are as follows:

1. Simpler operation with routine and repetitive functions programmed for automatic operation.
2. Reduced operator training time through on-screen instructions and supporting graphic displays.
3. Faster and better responsiveness to occupant needs and trouble conditions.
4. Reduced energy cost through centralized management of control and energy management programs.
5. Better management of the facility through historical records, maintenance management programs, and automatic alarm reporting.
6. Flexibility of programming for facility needs, size, organization, and expansion requirements.
7. Improved operating-cost record keeping for allocating to cost centers and/or charging individual occupants.
8. Improved operation through software and hardware integration of multiple subsystems such as direct digital control (DDC), fire alarm, security, access control, or lighting control.

When minicomputers and mainframes were the only computers available, the BMS was only used on larger office buildings and college campuses. With the shift to microprocessor-based controllers for DDC, the cost of integrating BMS functions into the controller is so small that a BMS is a good investment for commercial buildings of all types and sizes.

Some other benefits of BMSs shall be expressed as follows: [16]

A. *MONITORING:* Constant monitoring of the plant, and ability to recall the monitored data at a later time. This has enables engineers and technicians to achieve a better understanding of their buildings and plant and has often led to plant improvements and energy saving as a result. Energy efficiency can be checked as a BMS can monitor and log data from fuel & electricity meters.

B. *COMMUNICATION:* Developments on personal computers and internet technology led BMS to communicate from anywhere. By web server function operator can reach to site from anywhere in the world.

C. *MANPOWER SAVINGS & MAINTENANCE:* The local boilerman, caretaker or plant operator can often be replaced by communicating BMS outstation, or one operator can cover more buildings. Especially maintenance contractors and energy management bureaus offer to run clients' buildings and plant for them using outstations communicating regularly with the central station at the organizations headquarters.

D. *COMMISSIONING:* BMSs are becoming used in aiding the commissioning of plant in newly constructed buildings. This is rather used in large air conditioned office blocks with many small outstations on the air conditioning units around the building.

Some problems with BMSs shall be expressed as follows:

1. Associated with computers.
2. Large user manuals to explain many functions and operations that they can perform. User manuals are also not user friendly.
3. Training courses are expensive.
4. Software has continuously new versions to adapt.

5. The manipulation of energy data for monitoring and targeting the buildings is also a problem. A survey in 1990[17, 16] of 50 energy managers showed that 82% had BMS but only 2% could use them for targeting.
6. Clearly, BMSs are not being used to their full potential.
7. Incompatible devices and protocols from different manufacturers and problems to communicate the devices.

3.2 Background

The BMS concept emerged in the early 1950s and has since changed dramatically both in scope and system configuration. System communications evolved from hardwired (and homerun piping for pneumatic centralization) to multiplexed (shared wiring) to today's two-wire all digital system. The Energy Management System (EMS) and BMCS evolved from poll-response protocols with central control processors to peer-to-peer protocols with distributed control.

3.3 Energy Management

Energy management is typically a function of the microprocessor-based Direct Digital Controller (DDC). In most mid-sized to large buildings, energy management is an integral part of the BMCS, with optimized control performed at the system level and with management information and user access provided by the BMS host. Equipment is operated at a minimum cost and temperatures are controlled for maximum efficiency within user-defined comfort boundaries by a network of controllers. Energy strategies are global and network communications are essential.

Load leveling and demand control along with starting and loading of central plant based upon the demands of air handling systems require continuous global system coordination [18]. Energy Management BMS host functions include the followings:

1. Efficiency monitoring and recording.
2. Energy usage monitoring and recording.
3. Energy summaries.

    a. Energy usage by source and by time period.
    b. On-times, temperatures, efficiencies by system, building, area.
4. Curve plots of trends.
5. Access to energy management strategies for continuous tuning and adapting to changing needs.
    a. Occupancy schedules.
    b. Comfort limit temperatures.
    c. Parametric adjustments (e.g., integral gain) of DDC loops.
    d. Setpoint adjustments.
        i. Duct static pressures.
        ii. Economizer changeover values.
        iii. Water temperatures and schedules.
6. Modifying and adding DDC programs Energy Management for buildings preceded DDC by about ten years.

These pre-DDC systems were usually a digital architecture consisting of a central computer which contained the monitoring and control strategies and remote Data Gathering Panels (DGPs) which interfaced with local pneumatic, electric, and electronic control systems. The central computer issued optimized start/stop commands and adjusted local loop temperature controllers.

3.4 Facilities Management Systems

Facilities management, introduced in the late 1980s, broadened the scope of central control to include the management of a total facility. In an automotive manufacturing plant, for example, production scheduling and monitoring can be included with normal BMS environmental control and monitoring. The production and BMS personnel can have separate distributed systems for control of inputs and outputs, but the systems are able to exchange data to generate management reports. For example, a per-car cost allocation for heating, ventilating, and air conditioning overhead might be necessary management information for final pricing of the product.

Facilities management system configuration must deal with two levels of operation: day-to-day operations and long-range management and planning. Day-to-day operations require a real-time system for constant monitoring and control of the environment and facility. The management and planning level requires data and reports that show long-range trends and progress against operational goals. Therefore, the primary objective of the management and planning level is to collect historical data, process it, and present the data in a usable format. The development of two-wire transmission systems, PCs for centralized functions, and distributed processors including DDC led to a need to define system configurations. These configurations became based on the needs of the building and the requirements of the management and operating personnel.

1. System functions general.
2. Zone-level controller functions.
3. System-level controller functions.
4. Operations-level functions general.
    a. Hardware.
    b. Software.
        i. Standard Software.
        ii. Communications Software.
        iii. Server.
        iv. Security.
        v. Alarm Processing.
        vi. Reports.
        vii. System Text.
        viii. System Graphics.
        ix. Controller Support.

Chapter 4

BASIS OF AUTOMATIC CONTROL-THEORETICAL STUDY

4.1 Introduction

Automatic controls are used wherever a variable condition must be controlled. In HVAC systems, the most commonly controlled conditions are pressure, temperature, humidity, and rate of flow. Applications of automatic control systems range from simple residential temperature regulation to precision control of industrial processes [19].

4.2 Control Modes

Control systems use different control modes to accomplish their purposes. Control modes in commercial applications include two-position, step, and floating control; proportional, proportional-integral, and proportional – integral - derivative control; and adaptive control.

4.2.1 Two-Position Control

In two-position control, the final control element occupies one of two possible positions except for the brief period when it is passing from one position to the other. Two-position control is used in simple HVAC systems to start and stop electric motors on unit heaters, fan coil units, and refrigeration machines, to open water sprays for humidification, and to energize and de-energize electric strip heaters. Basic two-position control works well for many applications. For close temperature control, however, the cycling must be accelerated or timed.

4.2.1.1 Basic Two-Position Control

In basic two-position control, the controller and the final control element interact without modification from a mechanical or thermal source. The result is cyclical operation of the controlled equipment and a condition in which the controlled variable cycles back and forth between two values (the on and off points) and is influenced by the lag in the system (Figure 4.1). The controller cannot change the position of the final control element until the controlled variable reaches one or the other of the two limits of the differential. For that reason, the differential is the minimum possible swing of the controlled variable.

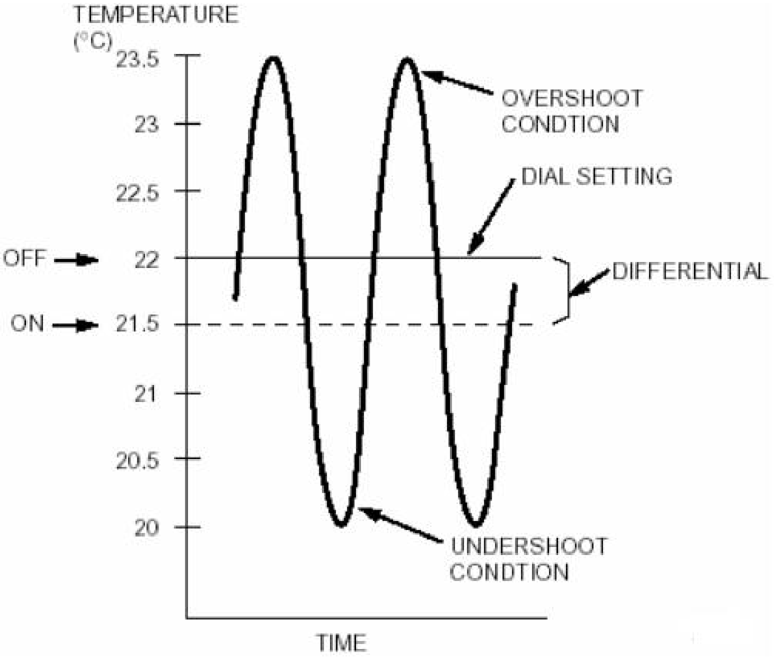


Figure 0.1. Basic two-position control

In basic two-position control, the presence of lag causes the controller to correct a condition that has already passed rather than one that is taking place or is about to take place. Consequently, basic two-position control is best used in systems with minimal total system lag (including transfer, measuring, and final control element lags) and where close control is not required.

4.2.2 Step Control

Step controllers operate switches or relays in sequence to enable or disable multiple outputs, or stages, of two-position devices such as electric heaters or reciprocating refrigeration compressors. Step control uses an analog signal to attempt to obtain an analog output from equipment that is typically either on or off Figure 4.2 show that the stages may be arranged to operate with or without overlap of the operating (on/off) differentials. In either case, the typical two-position differentials still exist but the total output is proportioned.

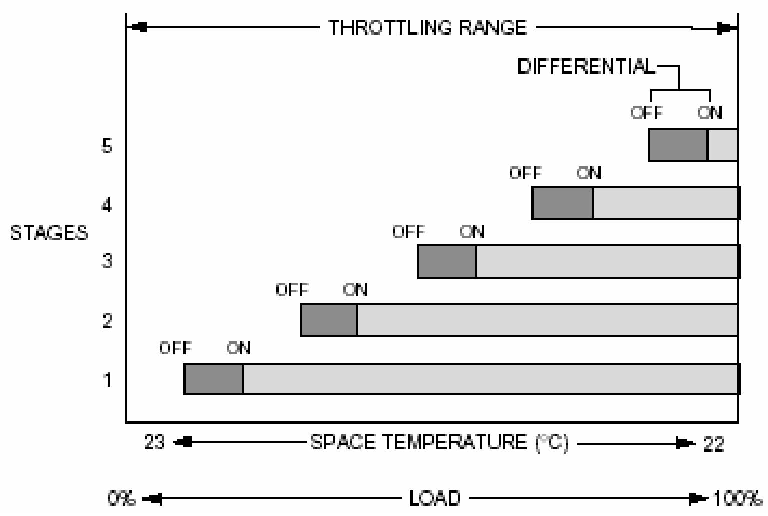


Figure 0.2. Electric heat stages

4.2.3 Floating Control

Floating control is a variation of two-position control and is often called *three-position control*. Floating control is not a common control mode, but is available in most microprocessor based control systems.

Floating control requires a slow-moving actuator and a fast responding sensor selected according to the rate of response in the controlled system. If the actuator should move too slowly, the controlled system would not be able to keep pace with sudden changes; if the actuator should move too quickly, two position control would result.

Floating control keeps the control point near the setpoint at any load level, and can only be used on systems with minimal lag between the controlled medium and the control sensor. Floating control is used primarily for discharge control systems where the sensor is immediately downstream from the coil, damper, or device that it controls. An example of floating control is the regulation of static pressure in a duct (Figure 4.3)

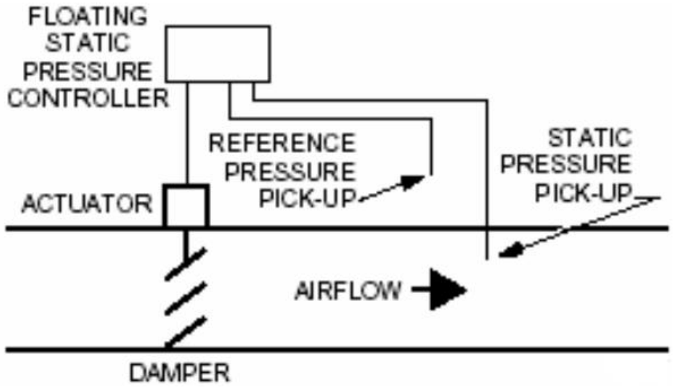


Figure 0.3. Floating static pressure control

In a typical application, the control point moves in and out of the deadband, crossing the switch differential (Figure 4.4). A drop in static pressure below the controller setpoint causes the actuator to drive the damper toward open. The narrow differential of the controller stops the actuator after it has moved a short distance. The damper remains in this position until the static pressure further decreases, causing the actuator to drive the damper further open. On a rise in static pressure above the setpoint, the reverse occurs. Thus, the control point can float between open and closed limits and the actuator does not move. When the control point moves out of the deadband, the controller moves the actuator toward open or closed until the control point moves into the deadband again.

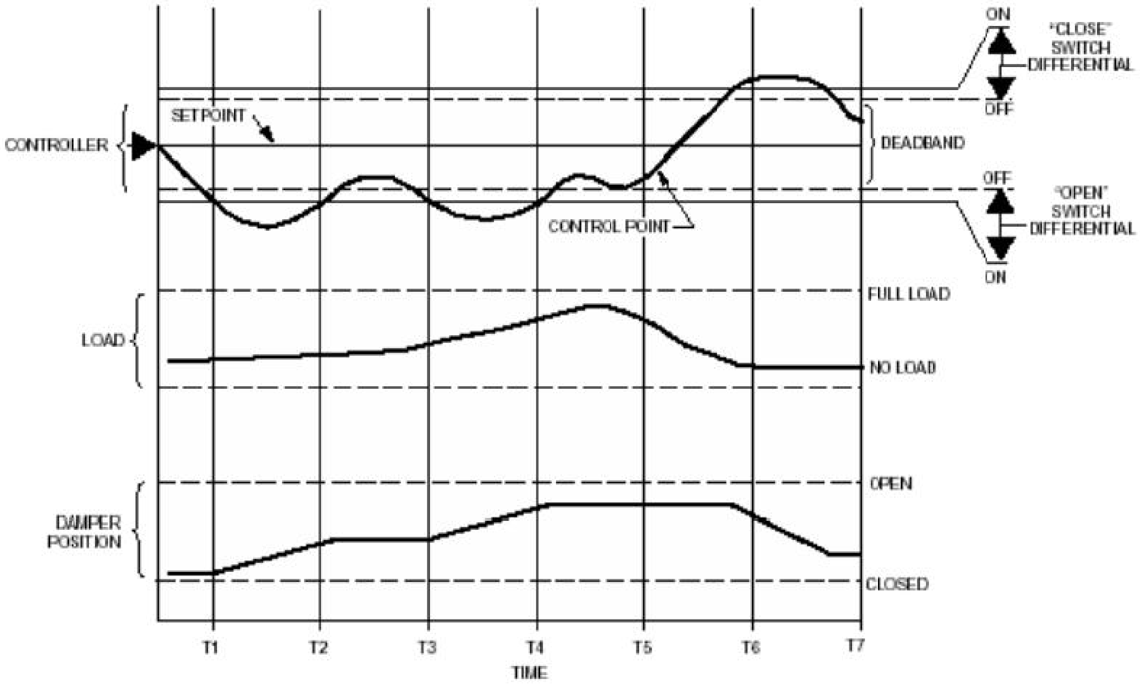


Figure 0.4. Floating control

4.2.4 Proportional Control

Proportional control proportions the output capacity of the equipment (e.g., the percent a valve is open or closed) to match the heating or cooling load on the building, unlike two-position control in which the mechanical equipment is either full on or full off. In this way, proportional control achieves the desired heat replacement or displacement rate.

In proportional control, the final control element moves to a position proportional to the deviation of the value of the controlled variable from the setpoint. The position of the final control element is a linear function of the value of the controlled variable (Figure 4.5)

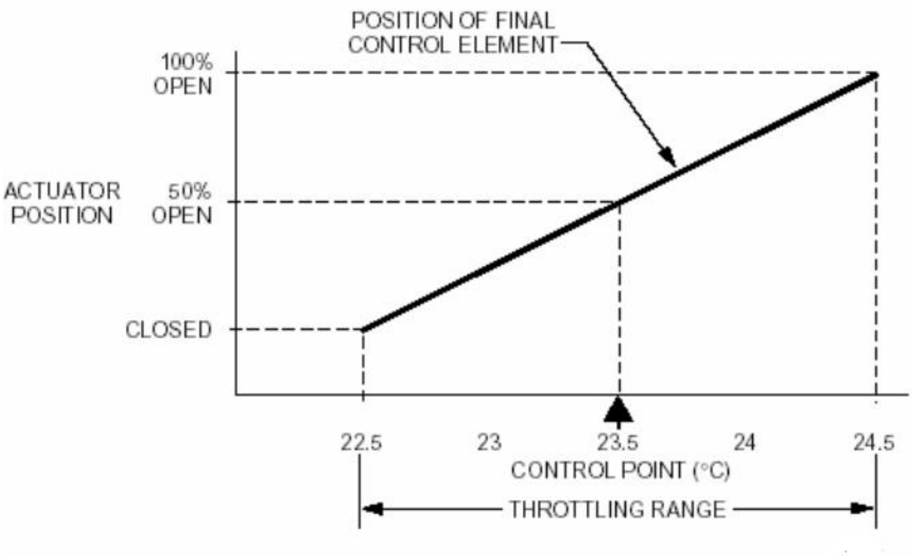


Figure 0.5. Final control element position as a function of the control point cooling system.

The final control element is seldom in the middle of its range because of the linear relationship between the position of the final control element and the value of the controlled variable.

In proportional control systems, the setpoint is typically the middle of the throttling range, so there is usually an offset between control point and setpoint.

The throttling range is the amount of change in the controlled variable required for the controller to move the controlled device through its full operating range. The amount of change is expressed in degrees Kelvin for temperature, in percentages for relative humidity, and in Pascal or kilopascal for pressure. For some controllers, throttling range is referred to as “proportional band”. Proportional band is throttling range expressed as a percentage of the controller sensor span:

$$\text{Proportional Band} = \frac{\text{Throttling Range}}{\text{Sensor Span}} x100$$

“Gain” is a term often used in industrial control systems for the change in the controlled variable. Gain is the reciprocal of proportional band:

$$Gain = \frac{100}{\text{Proportional Band}}$$

The output of the controller is proportional to the deviation of the control point from setpoint. A proportional controller can be mathematically described by:

$$V = KE + M$$

Where:

V = output signal
K = proportionality constant (gain)
E = deviation (control point - setpoint)
M = value of the output when the deviation is zero

(Usually the output value at 50 percent or the middle of the output range. The generated control signal correction is added to or subtracted from this value. Also called "bias" or "manual reset".)

4.2.5 Proportional-Integral (PI) Control

In the proportional-integral (PI) control mode, reset of the control point is automatic. PI control, also called "proportional plus - reset" control, virtually eliminates offset and makes the proportional band nearly invisible. As soon as the controlled variable deviates above or below the setpoint and offset develops, the proportional band gradually and automatically shifts, and the variable is brought back to the setpoint. The major difference between proportional and PI control is that proportional control is limited to a single final control element position for each value of the controlled variable. PI control changes the final control element position to accommodate load changes while keeping the control point at or very near the setpoint.

The reset action of the integral component shifts the proportional band as necessary around the setpoint as the load on the system changes. The graph in Figure 4.6 shows the shift of the proportional band of a PI controller controlling a normally open heating valve. The shifting of the proportional band keeps the control point at setpoint by making further corrections in the control signal. Because offset is eliminated, the proportional band is usually set fairly wide to ensure system stability under all operating conditions.

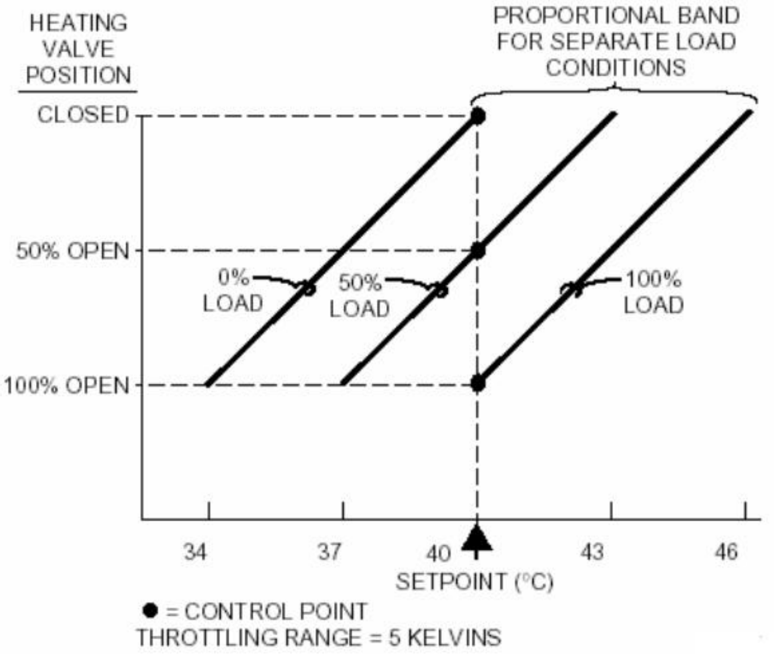


Figure 0.6. Proportional band shift due to offset

Reset of the control point is not instantaneous. Whenever the load changes, the controlled variable changes, producing an offset. The proportional control makes an immediate correction, which usually still leaves an offset. The integral function of the controller then makes control corrections over time to bring the control point back to setpoint (Figure 4.6). In addition to a proportional band adjustment, the PI controller also has a reset time adjustment that determines the rate at which the proportional band shifts when the controlled variable deviates any given amount from the setpoint.

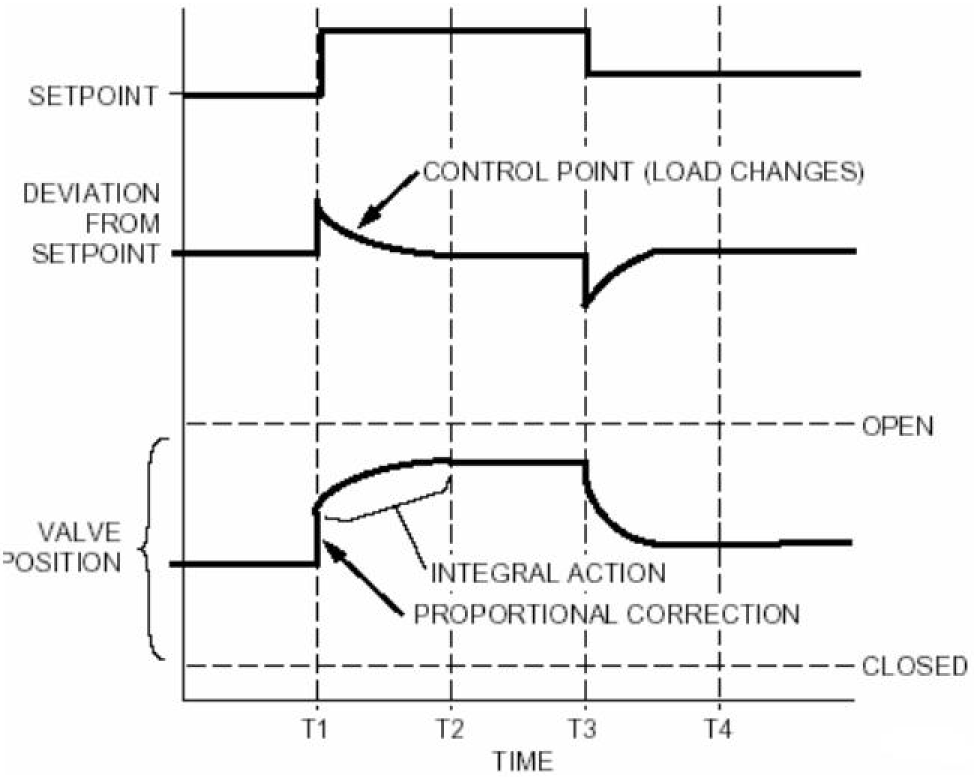


Figure 0.7. Integral action

Reset error correction time is proportional to the deviation of the controlled variable. For example, a four-percent deviation from the setpoint causes a continuous shift of the proportional band at twice the rate of shift for a two-percent deviation. Reset is also proportional to the duration of the deviation. Reset accumulates as long as there is offset, but ceases as soon as the controlled variable returns to the setpoint.

With the PI controller, therefore, the position of the final control element depends not only upon the location of the controlled variable within the proportional band (proportional band adjustment) but also upon the duration and magnitude of the deviation of the controlled variable from the setpoint (reset time adjustment). Under steady state conditions, the control point and setpoint are the same for any load conditions, as shown in Figure 4.7.

PI control adds a component to the proportional control algorithm and is described mathematically by:

$$V = K.E.\frac{K}{T_1}\int E.dT + M$$

Where:

V = output signal
K = proportionality constant (gain)
E = deviation (control point - setpoint)
T1 = reset time
K/T1 = reset gain
Dt = differential of time (increment in time)
M = value of the output when the deviation is zero

Integral windup, or an excessive overshoot condition, can occur in PI control. Integral windup is caused by the integral function making a continued correction while waiting for feedback on the effects of its correction. While integral action keeps the control point at setpoint during steady state conditions, large overshoots are possible at start-up or during system upsets (e.g., setpoint changes or large load changes). On many systems, short reset times also cause overshoot.

Integral windup may occur with one of the following:

- When the system is off.
- When the heating or cooling medium fails or is not available.
- When one control loop overrides or limits another.

Integral windup can be avoided and its effects diminished. At start-up, some systems disable integral action until measured variables are within their respective proportional bands. Systems often provide integral limits to reduce windup due to load changes. The integral limits define the extent to which integral action can adjust a device (the percent of full travel). The limit is typically set at 50 percent.

4.2.6 Proportional-Integral-Derivative (PID) Control

Proportional-integral-derivative (PID) control adds the derivative function to PI control. The derivative function opposes any change and is proportional to the rate of change. The more quickly the control point changes, the more corrective action the derivative function provides.

If the control point moves away from the setpoint, the derivative function outputs a corrective action to bring the control point back more quickly than through integral action alone. If the control point moves toward the setpoint, the derivative function reduces the corrective action to slow down the approach to setpoint, which reduces the possibility of overshoot.

The rate time setting determines the effect of derivative action. The proper setting depends on the time constants of the system being controlled. The derivative portion of PID control is expressed in the following formula. Note that only a change in the magnitude of the deviation can affect the output signal.

$$V = K.T_D \frac{dE}{dT}$$

Where:

V = output signal
K = proportionality constant (gain)
TD = rate time (time interval by which the derivative advances the effect of proportional action)
KTD = rate gain constant
dE/dT = derivative of the deviation with respect to time (error signal rate of change)

The complete mathematical expression for PID control becomes:

$$V = K.E + \int E.dT + K.T_D \frac{dE}{dT} + M$$

Where:

V = output signal
K = proportionality constant (gain)
E = deviation (control point - setpoint)
T1 = reset time
K/T1 = reset gain
Dt = differential of time (increment in time)
TD = rate time (time interval by which the derivative advances the effect of proportional action)
KTD = rate gain constant

dE/dt = derivative of the deviation with respect to time (error signal rate of change)

M = value of the output when the deviation is zero

The graphs in Figure 4.8, Figure 4.9 and Figure 4.10 show the effects of all three modes on the controlled variable at system start-up. With proportional control (Fig. 11), the output is a function of the deviation of the controlled variable from the setpoint. As the control point stabilizes, offset occurs. With the addition of integral control (Fig. 12), the control point returns to setpoint over a period of time with some degree of overshoot. The significant difference is the elimination of offset after the system has stabilized. Figure 13 shows that adding the derivative element reduces overshoot and decreases response time.

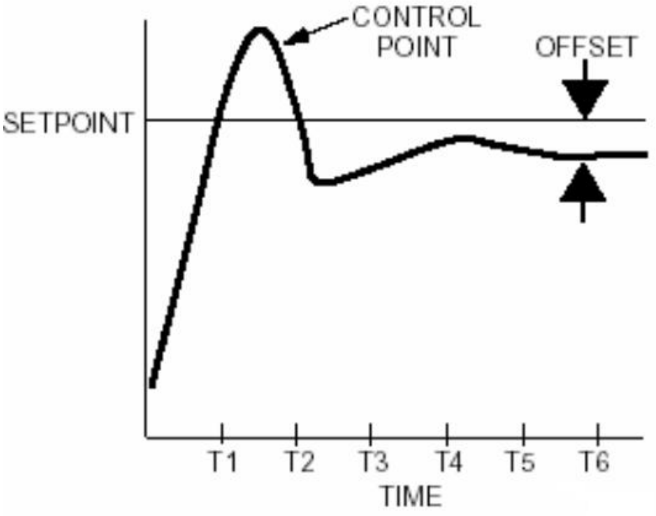


Figure 0.8. Proportional control

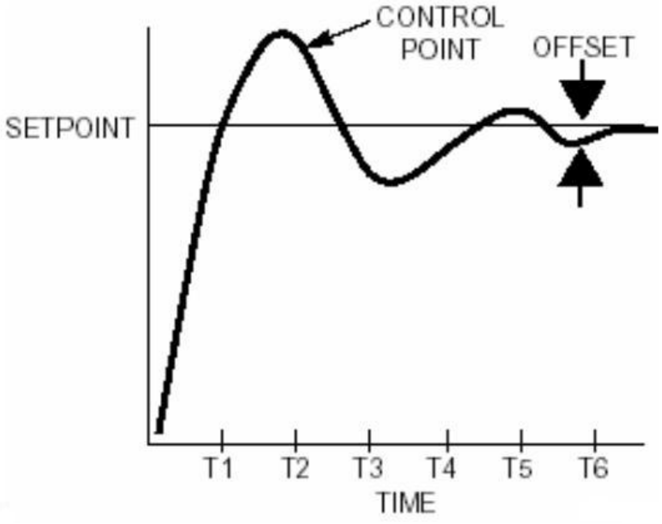


Figure 0.9. Proportional-Integral control

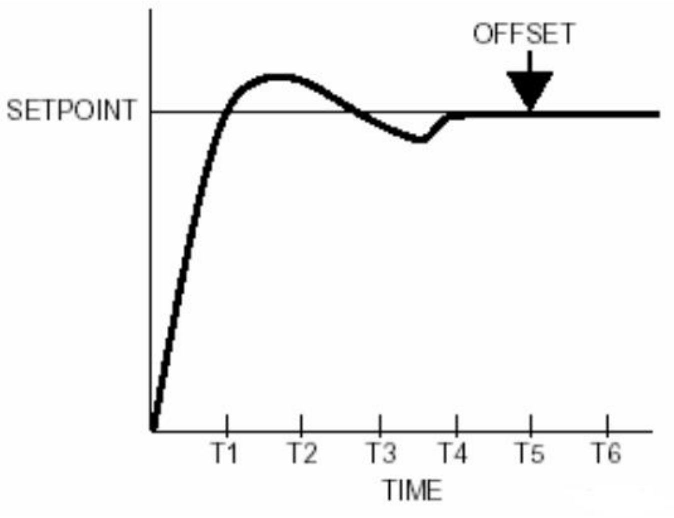


Figure 0.10. Proportional-Integral-Derivative control

Chapter 5

HVAC CONTROL PRINCIPLES FOR ENERGY CONSERVATION

After the general needs of a building have been established, and building and system subdivision has been made, the mechanical system and its control approach can be considered. Designing systems that conserve energy requires knowledge of the building, its operating schedule, the systems to be installed, and ASHRAE Standard 90.1.(A set of requirements for the energy efficient design of commercial buildings).

Care must be taken while following energy conservation strategies. HVAC systems are non-linear and characteristics changes on a seasonal basis so implemented strategies might cause to consume more energy in the following season. Because of that all implemented strategies shall be checked for seasonal changes. Main HVAC control principles or approaches that conserve energy are as follows:

5.1 Supplying Heating and Cooling From the Most Efficient Source

Free or low-cost energy sources such as solar and geothermal energy should be used first, and then higher cost sources as necessary. If electric prices are time-scheduled, high demand loads should be used in the cheapest time-schedule.

5.2 Running Equipment Only When Needed

HVAC unit operation shall be scheduled for occupied periods. Morning warm-up can be started as late as possible to achieve design internal temperature by occupancy time, considering residual space temperature, outdoor temperature, and equipment capacity (optimum start control). Under most conditions, equipment can be shut down some time before the end of occupancy, depending on internal and external load and space temperature (optimum stop control). Shutdown time shall be calculated so that space temperature does not drift out of the selected comfort zone before the end of occupancy. Heating shall be started at night only to maintain internal temperature between 10 and 13°C to prevent freezing.

5.2.1 Optimum Start

Based on measurements of indoor and outdoor temperatures and a historical multiplier adjusted by startup data from the previous day, the optimum start strategy (Figure 5.1) calculates a lead time to turn on heating or cooling equipment at the optimum time to bring temperatures to proper level at the time of occupancy. To achieve these results the constant volume Air Handling Unit (AHU) optimum start program delays AHU start as long as possible, while the Variable Air Volume (VAV) optimum start program often runs the VAV AHU at reduced capacity. Unless required by Indoor Air Quality (IAQ), outdoor air dampers and ventilation fans should be inactive during preoccupancy warm up periods. For weekend shutdown periods, the program automatically adjusts to provide longer lead times. This strategy adapts itself to seasonal and building changes.

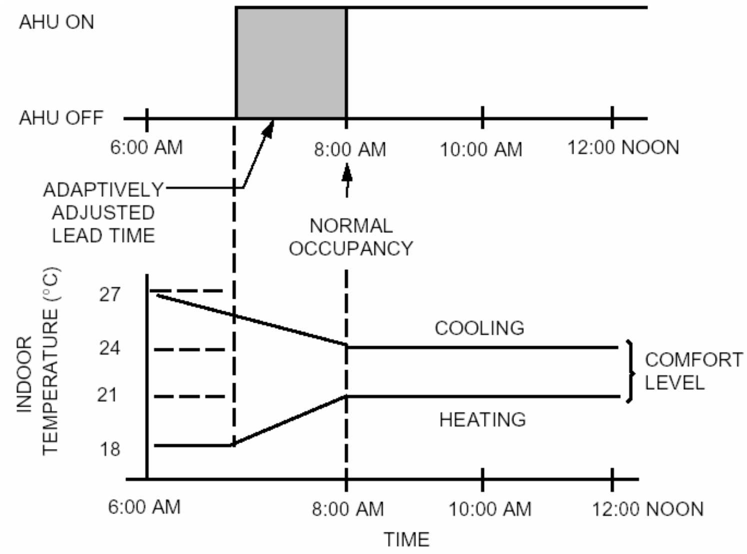


Figure 0.1. Optimum start

5.2.2 Optimum Stop

The optimum stop strategy (Figure 5.2) uses stored energy to handle the building load to the end of the occupancy period. Based on the zone temperatures that have the greatest heating and greatest cooling loads and the measured heating and cooling drift rates, the program adjusts equipment stop time to allow stored energy to maintain the comfort level to the end of the occupancy period. This program adapts itself to changing conditions.

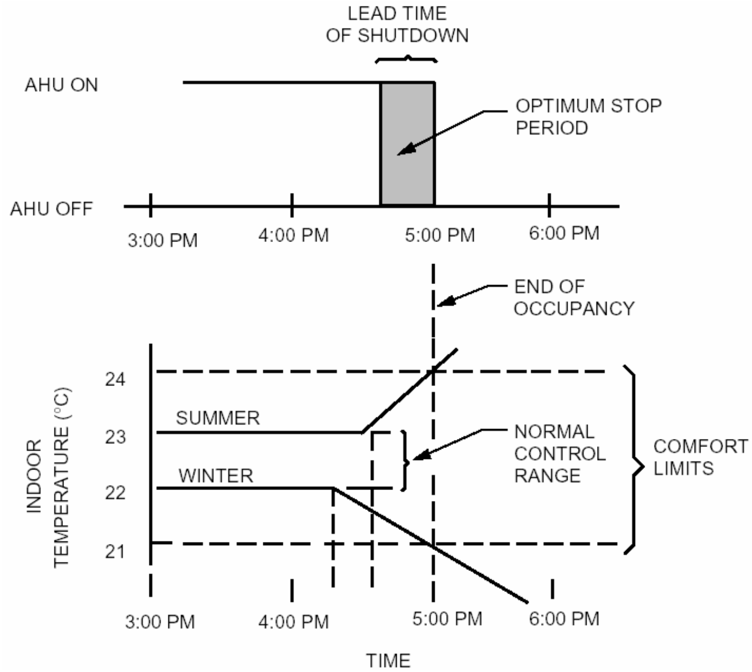


Figure 0.2. Optimum stop

5.2.3 Night Cycle

The night cycle strategy (Figure 5.3) maintains a low temperature limit in the heating season during unoccupied periods by cycling the air handling unit while the outdoor air damper is closed. Digital control systems often reduce fan capacity of VAV AHU systems to accomplish this and reduce energy usage.

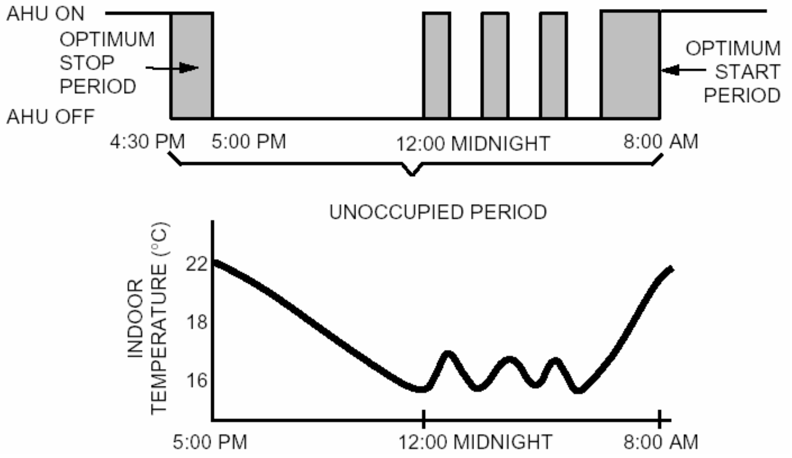


Figure 0.3. Night cycle

5.3 Sequencing Heating And Cooling

Heating and cooling should not be supplied simultaneously. Central fan systems should use cool outdoor air in sequence between heating and cooling. Zoning and system selection should eliminate, or at least minimize, simultaneous heating and cooling. Also, humidification and dehumidification should not take place concurrently.

5.3.1 Zero Energy Band

The zero energy band (Figure 5.4) strategy provides a dead band where neither heating nor cooling energy is used. This limits energy use by allowing the space temperature to float between minimum and maximum values. It also controls the mixed-air dampers to use available outdoor air if suitable for cooling. On multizone fan systems with simultaneous heating and cooling load capability, zone load reset controls the hot and cold deck temperature setpoints.

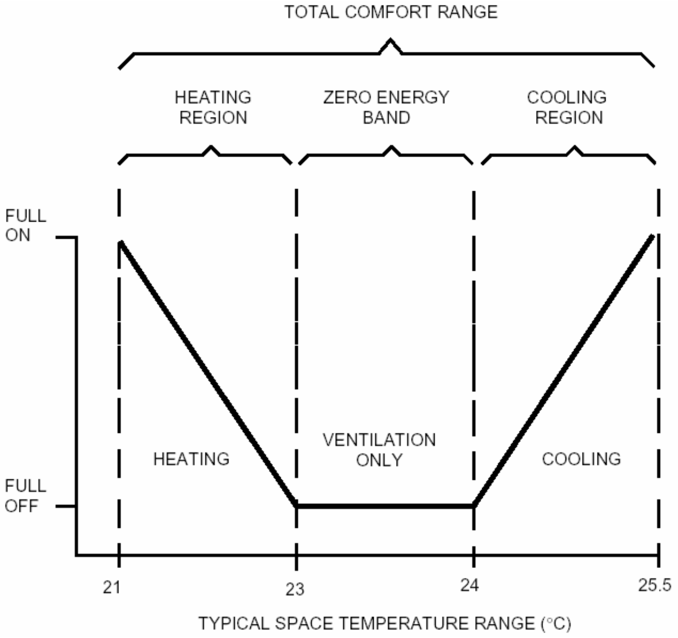


Figure 0.4. Zero energy band

5.3.2 Fan Control

This strategy works on the assumption that the supply fan of a space need not operate if the cooling and heating coil valves are closed during unoccupied times. And to be able to benefit from this strategy the dead band shall not be less then 2°C. This control strategy can therefore only be used during unoccupied space times. This control has a strategy for both cooling and heating sides. (Figure 5.5) As an example; for the cooling side, the fan is switched on when the cooling valve opens at 24.5°C. The fan will then stay on until the temperature drops 1°C below the opening temperature before it switches off. For the heating side the fan will switch on at 18°C. It will then switch off 1°C above the valve opening temperature. The supply fans must run at all times if the room is occupied. The return fans will operate in tandem with their correlating supply fans.

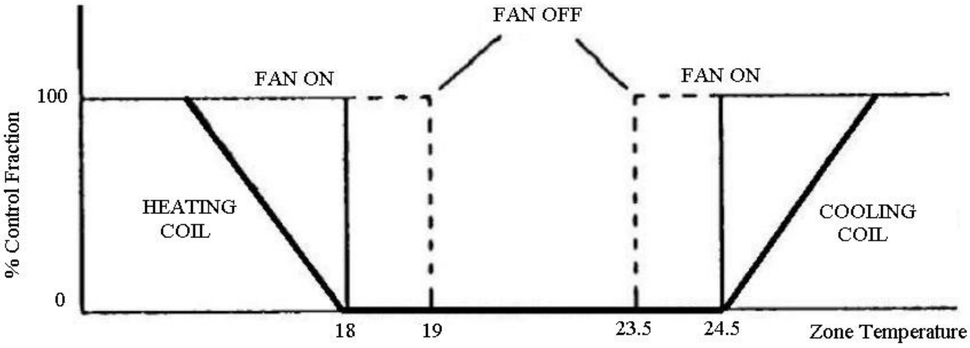


Figure 0.5. Fan control strategy for unoccupied space times

Fans can be turned off during the night and early mornings. This corresponds to the time when the building is not in use, and therefore does not need any air-conditioning. The operating times should differ for each zone, according to the times of use. The return air (RA) fans, which work in tandem with their relevant supply air fans, can therefore be switched off.

5.4 Applying Outdoor Air Control

Outdoor air shall be minimized, no less than mechanically designed air change ratio recommended by ASHRAE Standard 62 (Ventilation standard which specifies minimum ventilation rates and IAQ that will be acceptable and minimize potential adverse health effects.) should be used. In areas where it is cost-effective, enthalpy should be used rather than dry-bulb temperature to determine whether outdoor or RA is the most energy-efficient air source for the cooling mode.

For heating plant, setpoint shifting should be implemented due to outdoor air temperature. This strategy is called outdoor air compensation.

5.4.1 Outdoor Air Dry Bulb Temperature Control

Outdoor air is used for cooling anytime the OA temperature is below the setpoint. For successful operation, local weather data analysis needed to determine the optimum changeover setpoint. The analysis need only consider data when the OA is between approximately 16°C and 25.5°C, and during the occupancy period. The dry bulb economizer decision is best on small systems (where the cost of a good humidity sensor cannot be justified), where maintenance cannot be relied upon, or where there are not frequent wide variations in OA RH during the decision window (when the OA is between approximately 16°C and 25.5°C).

The minimum set for outdoor air damper shall not be considered if the space is not occupied. So this strategy can be divided into two parts, an occupied strategy and an unoccupied strategy. Infrared motion detectors should be located in the space which will be responsible for selecting the relevant strategy. The occupied strategy will be active for 15 min after movement was detected by any of the sensors in the space. This implies that the timer will reset itself if new movement is detected during this period and the 15-min countdown will start all over again. The unoccupied strategy will therefore only be activated when all the sensors in the space are passive for a period of 15 min. For this option all the relevant motion detectors of the space which RA to the same set of dampers must be passive for 15 min to activate the unoccupied economizer control strategy.

5.4.1.1 Occupied strategy

If the RA temperature is higher than the outdoor air temperature the following strategy will be followed as an example:

If the RA temperature exceeds 22°C the fresh air damper will open proportionally from its minimum setting (40% fresh air of total supply) until fully open at 23°C.For the same conditions the RA damper will start to close proportionally from its maximum setting (60% RA) to fully closed. (Figure 5.6)

If no cooling is required the fresh air damper will be at its minimum setting (40% fresh air) and the RA damper at its maximum (60% RA).If the outdoor air temperature exceeds the RA temperature the fresh air damper will close to its minimum setting (40% fresh air) and the RA to its maximum, 60% RA.

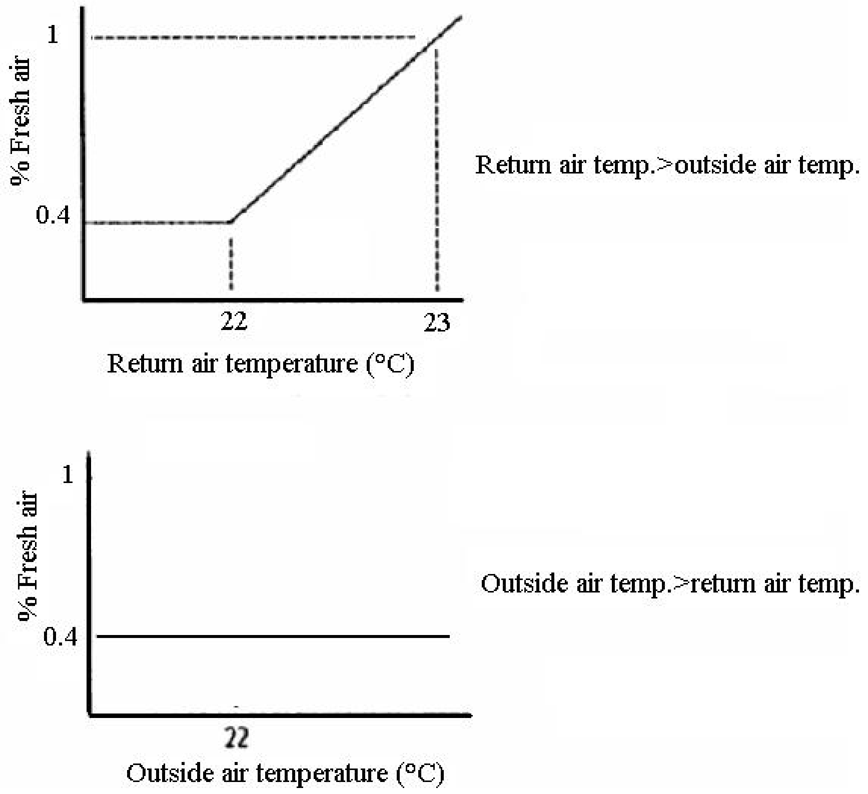


Figure 0.6. Occupied economizer control strategy

5.4.1.2 Unoccupied strategy

If the RA temperature is higher than the outdoor air temperature the following strategy must be followed as an example:

If the RA temperature exceeds 22.C the fresh air damper will open proportionally from its closed position (0% fresh air of total supply) until fully open at 23°C. The RA damper will for the same conditions start to close proportionally from its fully open position (100% RA) to fully closed (Figure 5.7).

If no cooling is required the fresh air damper will be closed and the RA damper fully open. If the outdoor air temperature exceeds the RA temperature the fresh air damper will close completely and the RA damper will be fully open.

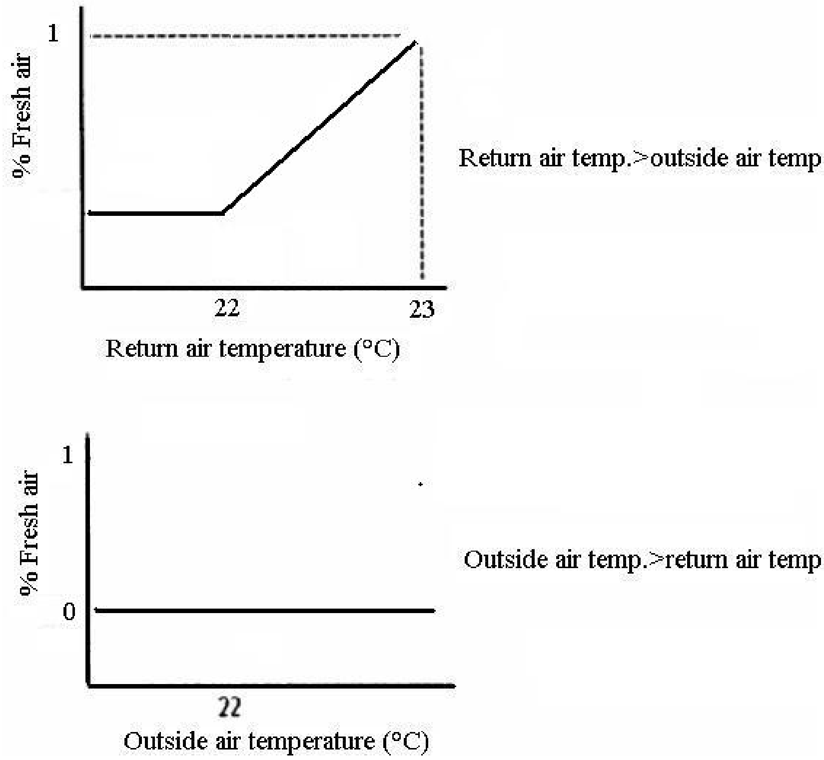


Figure 0.7. Unoccupied economizer control strategy

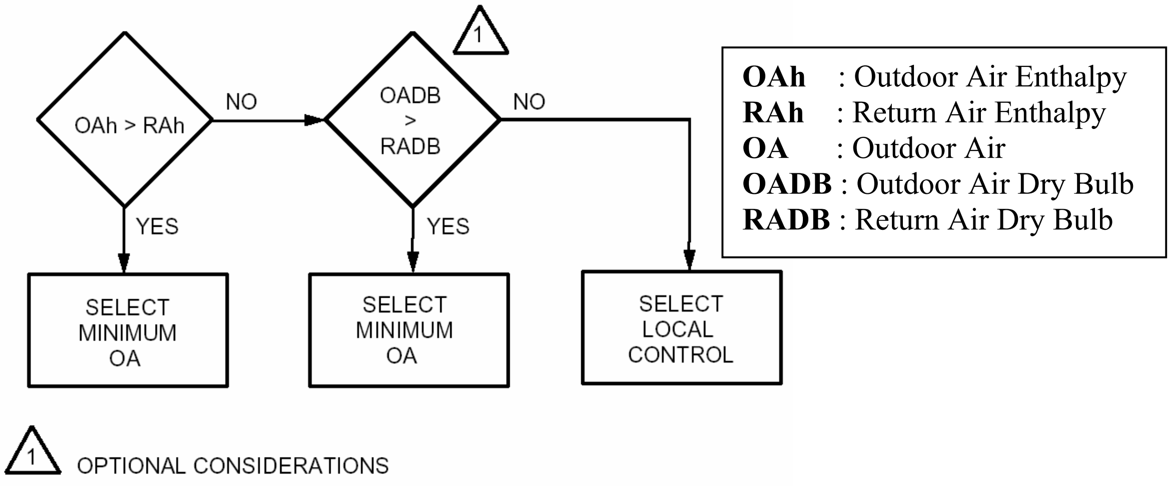
5.4.2 Outdoor Air Enthalpy Control

The enthalpy control (Figure 5.8) selects the air source that requires the least total heat (enthalpy) removal to reach the design cooling temperature. The selected air source is either the RA with a selectable minimum amount of outdoor air or a mixture of outdoor and RA as determined by local control from discharge-air or space temperature measurement. Measurements of RA enthalpy and RA dry bulb are compared to outdoor air conditions and used as criteria for the air source selection. A variation of this, although not recommended, is comparing the OA enthalpy to a constant (such as 63.96 kilojoules per kilogram of dry air) since the controlled RA enthalpy is rather stable.

For successful operation A high quality Relative Humidity (RH) sensor with at least 3% accuracy should be selected. An estimate of the typical RA enthalpy is needed to determine the optimum changeover setpoint. A high dry-bulb limit setpoint should be included to prevent the enthalpy decision from bringing in air too warm for the chilled water coil to cool down.

OA based upon an OA enthalpy calculation setpoint, except the system shall be locked out of the economizer mode anytime the OA dry bulb (DB) is higher than 27.5°C. Strategy shall also be provided to allow the user to switch, with an appropriate commandable setpoint, the decision to be based upon OA dry bulb or to lock the system into or out of the economizer mode.

Outdoor air is used for cooling (or to supplement the chilled water system) anytime the OA enthalpy is below the economizer setpoint. OA enthalpy considers total heat and will take advantage of warm dry low enthalpy OA and will block out cool moist OA, thus saving more energy than a dry-bulb based economizer loop.



OAh : Outdoor Air Enthalpy
RAh : Return Air Enthalpy
OA : Outdoor Air
OADB : Outdoor Air Dry Bulb
RADB : Return Air Dry Bulb

Figure 0.8. Enthalpy decision ladder

5.4.3 Night Purge

The night purge control strategy uses cool, night outdoor air to pre-cool the building before the mechanical cooling is turned on. Digital control systems often reduce fan capacity of VAV AHU systems during Night Purge to reduce energy usage. Outdoor temperature, outdoor RH or dew point, and space temperature are analyzed. One hundred percent outdoor air is admitted under the following typical conditions:

1. Outdoor air above a summer-winter changeover point, such as 10°C.
2. Outdoor temperature below space temperature by a specified RH or determined differential.
3. Outdoor air dew point less than 16°C.
4. Space temperature above some minimum for night purge such as 24°C.

5.4.4 Heating Plant Control with Outdoor Air Compensation

In general the heating plant control strives to keep the boiler water at 75°C throughout the year. The pump also runs right through the year. This wastes energy, as no heating needs to be done during the hot summer months of the year. To be able to reduce energy consumption the following boiler control strategy should be applied:

The boiler setpoint will be a second order function (Figure 5.9) of the average outdoor air temperature of the previous 24 h. [20] The outdoor air temperature will therefore be monitored and locked at half hour intervals. A new average outdoor air temperature will be calculated for each new half hour by taking he previous 48 locked temperature points. A new setpoint will then be calculated for each half hour of the day by the following function: setp=0:162t^2 - 8:857t + 139:18; where "setp" is the boiler set temperature in °C and t is the average outdoor air temperature in °C.

To reduce energy consumption of hot water pump, following control strategy should be applied: The pump will only start running when one of the heating coils requires hot water, in other words, when one of the heating coil's control valves open. If no heat is required the pump will shut down. To keep the pump from cycling, a time delay of 30 min can be incorporated before pump shut down can occur.

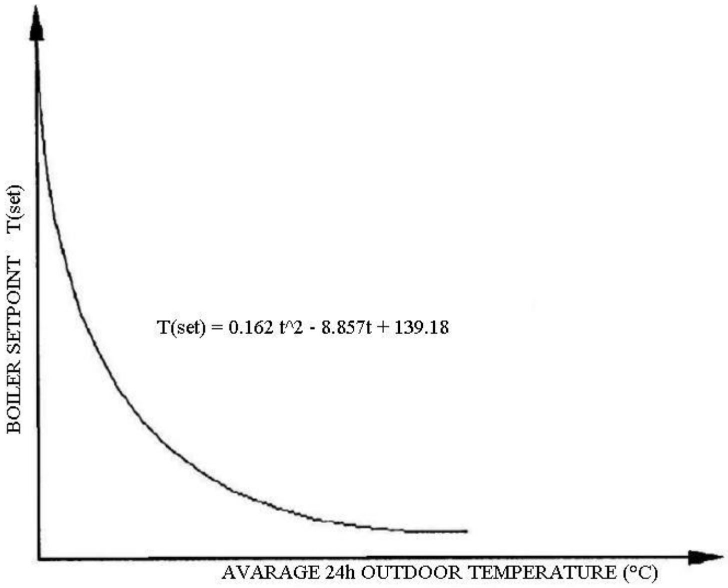


Figure 0.9. Heating plant control

5.5 Setting Back The Setpoint

This option allows setpoint drift if the rooms are unoccupied. This control strategy also requires the installation of motion sensors in the rooms. It operates on the assumption that a room does not need to be kept on setpoint if it is not in use. If a space is unoccupied, the control will let both the cooling and heating coil setpoints to drift to hotter and colder temperatures, respectively. (Figure 5.10) The zones will then require less cooling and heating from the HVAC system. For the unoccupied conditions the cooling coil will be fully open at 26°C and fully closed at 23.5°C. The heating coil will be fully open at 16.5°C and fully closed at 18°C.

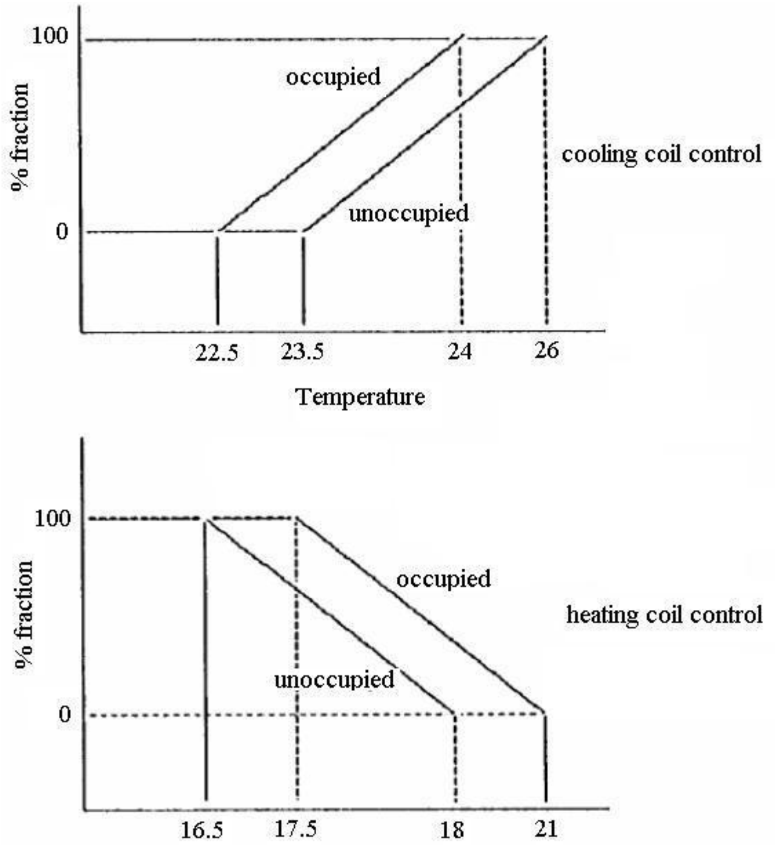


Figure 0.10. Setpoint setback control strategy

Another application for set point related strategy is to setback setpoint according to the building operating schedule. Multistage operation technique can be implemented (3 setpoints within a day) time-of-day operating schedule. Following building operation problem in a AHU should be considered. The 24 h operation of the building is divided into three stages: normal setback mode (stage 1) between 19:00 and 07:00 h, start-up mode (stage 2) between 07:00and 08:00 h and normal mode operation during the occupied period between 08:00 and 19:00 h (stage 3). In stage 3, both thermal comfort and energy efficiency are of prime concern, whereas in stage 1, energy efficiency is the main issue and in stage 2, fast response and energy efficiency are important considerations. During a typical day operation, the AHU system undergoes such a multistage sequence, consequently during each stage, some of the local control loops could be turned off or allowed to operate at fixed open loop position. For example, the outdoor air dampers could be closed in normal hours (stage 1). After defining the performance requirements for all three stages and appropriately choosing the local control loop tasks (closed, open loop or closed loop), the optimization problem to be solved is to determine an optimal operating strategy for the AHU system which meets the entire above requirement.

Chapter 6

CASE STUDY – OZDILEK SHOPPING CENTER (OSC)

6.1 Introduction

A case study is carried out in OSC to investigate the potential for energy savings and to redefine control parameters for HVAC system in the building. An energy audit was conducted according to “Washington State University Energy Program, Energy Audit Workbook” (APPENDIX A) to determine the end-user breakdown of the energy consumption in the shopping center. Outcome of this audit was used to identify the largest energy consumers, which are usually also the areas with the largest energy savings potential. The measuring of the energy utilization of the shopping center has been a very labour intensive process.

To carry out the case study systematically methodology is developed (Figure 6.1). Case study started with a “walk through” audit to identify the energy usage of HVAC equipment, lights and other diverse equipment. Then a detailed study was carried out to reach regular and reliable records of energy use to understand and control the energy management strategy. These records helped to identify changes in energy costs and consumption. Performance evaluation of the building is determined and compared with the accepted standards. Normalized performance indices calculated to measure building’s efficiency better. Then an action plan was identified to implement the HVAC control strategies to reduce energy consumption. Actual control strategies and parameters are analyzed. Fluctuations from the setpoints are determined. New strategies and parameters are implemented to two AHUs. Results are compared with the proceeding values.

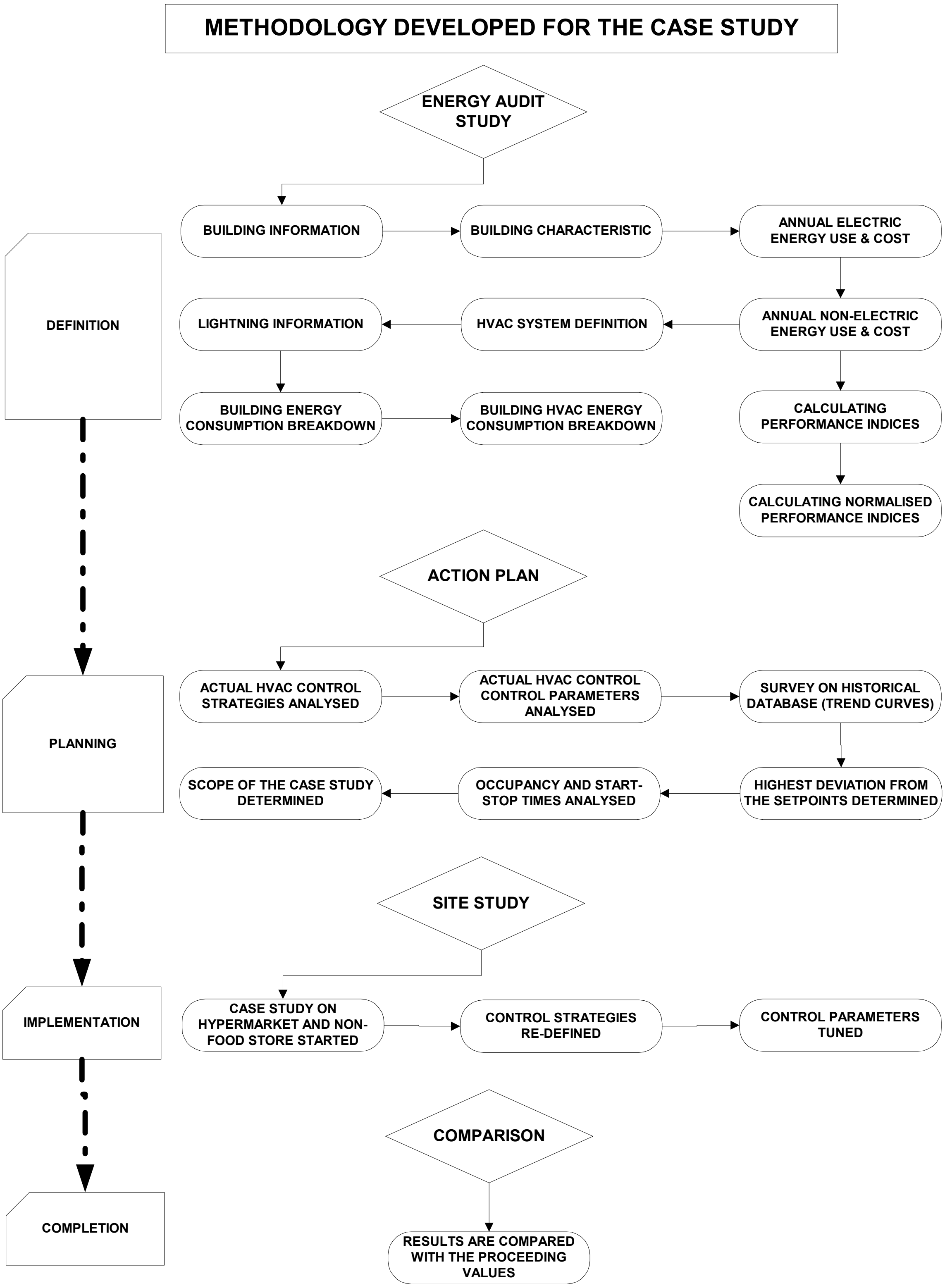


Figure 0.1. Methodology developed for the case study

6.2 Energy Audit

To investigate energy saving potentials it is needed to analyze OSC energy usage. Questionnaires were made and detailed investigation on electricity and Liquid Petroleum Gas (LPG) invoices were done.

To initialize the energy audit study building information and building characteristics were analyzed. This study included occupancy profiles and architectural locations of HVAC zones. Then HVAC system defined and energy consumption breakdown of the building were generated. This was very helpful to compare electricity and fossil fuel consumptions. To be able to understand the fluctuations of energy consumption, annual energy usage for electricity and LPG is plotted. Within this study HVAC energy consumption is focused and various component of the HVAC energy consumption is analyzed.

These studies are not enough to understand the building energy performance. So performance indices are calculated and compared with the yardsticks. Then normalized performance indices are calculated. Assessing the energy performance of this building also allows us to:

1. Compare performance of the building with standards to suggest the potential for energy saving in the building.
2. Compare with other buildings in an estate or group of buildings to help identify which should be investigated first.
3. Compare with performance in previous years to monitor progress and to assess the effects of any changes or energy saving measures.
4. Consider the energy use in more depth to help understand where energy is used and wasted, and hence where savings are most likely to be made

The OCS has an ongoing non-systematic energy management program. These studies are very helpful to compose the database for this energy audit. Facility management of the shopping center is trying to coordinate the LPG usage and lightning. They also conduct periodic maintenance to industrial refrigeration units, energy distribution panels (preventing arc hazards), chilling units, AHU's, water distribution pumps and boilers.

Based on the questionnaires the energy utilization of the shopping center is 4,360,000 kWh/year and within the current energy management studies approximate energy saving is 655.000 kWh/year (~ 15%). This saving depends on operators and should be at least 20%.

Conservation measures (retrofit) already implemented or under consideration prior to this audit is as follows:

- Optimum start/stop depending on occupancy (assumed fixed values per days and hours).
- Free outside cooling manually.
- Automatic shut-down doors between heating zones.
- Automatic doors in warehouse.
- Warning signs to save energy for LPG usage.
- Reducing heat transfer with air curtains.

6.2.1 Building Information and Characteristics

OSC is located in Inciraltı/Izmir, Turkey. The building consists of five air-conditioned zones with approximately 16,000 m^2 floor area; hypermarket, café & restaurant and starpark (children playground) are on the ground floor (Figure 6.2), non-food store and offices are on the first floor (Figure 6.3). The building has south-east and south-west facing windows, with conventional glazing.

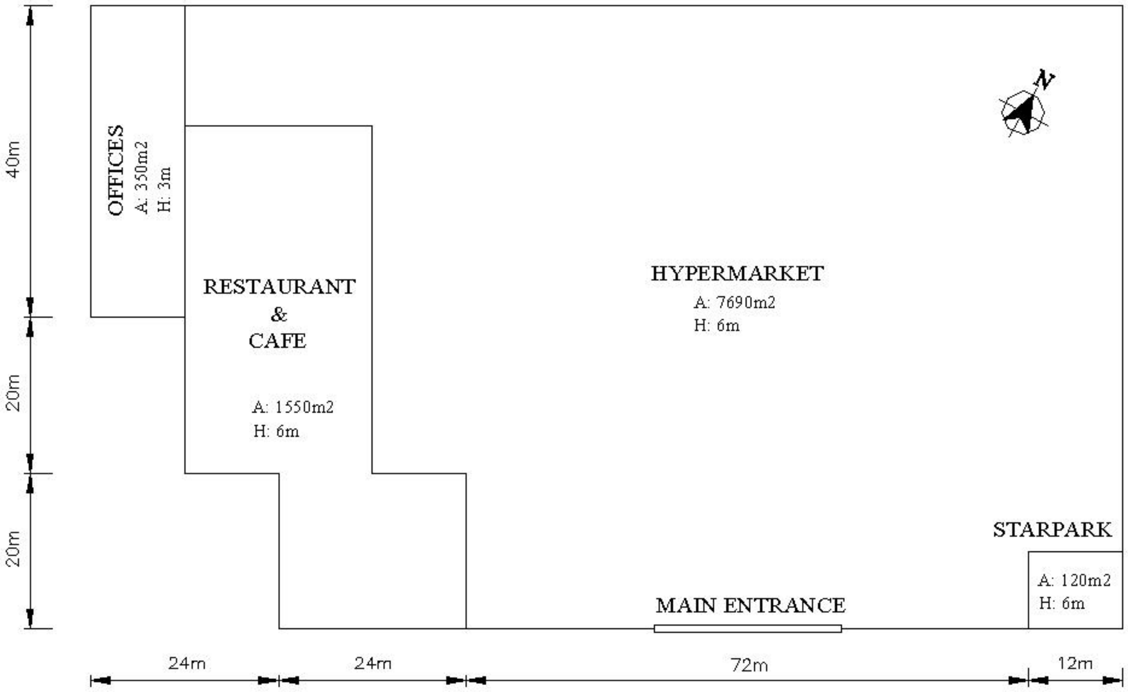


Figure 0.2. OSC ground floor

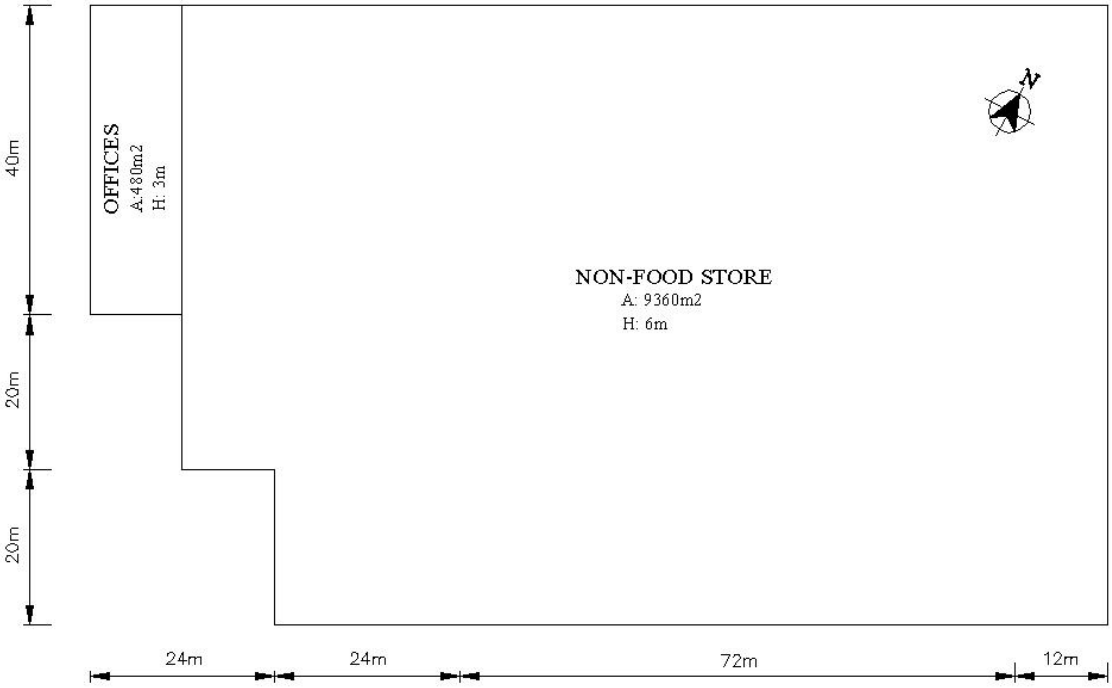


Figure 0.3. OSC first floor

All offices have adjustable external venetian blind for shading on the office windows. The building's office windows face towards south-west. Each office is air-conditioned by its own fan coil unit (FCU).

Lighting is done by fluorescent bulbs in the offices as well as in the hypermarkets. Most of the offices are equipped with computers.

OSC houses an average of 11,000 people per day on weekdays and 20,000 people/day on weekends. Working hours and occupancy schedule of the zones are shown in Table 6.1. Hypermarket has the great potential for occupancy on weekends. Building occupancy profile should give us an idea to refresh the HVAC control strategies due to daily, weekly and annual profiles of the occupancy. Figures 6.4, 6.5 and 6.6 shows daily, weekly and monthly building occupancy profile. Setpoints and working hours should be redefined according to these figures.

Table 0.1. Building occupancy schedule

Area / Zone	**m^2**	**Week Days**			**Weekends, Holidays**		
		Hours		**# of People**	**Hours**		**# of People**
		From	**To**		**From**	**To**	
Hypermarket	7,690	10:00	24:00	5,000	10:00	24:00	9,000
Non-Food Store	9,360	10:00	24:00	3,500	10:00	24:00	7,500
Café & restaurant	1,550	10:00	24:00	2,000	10:00	24:00	3,500
Offices	1830	08:00	08:00	270	08:00	08:00	320
Starpark	120	10:00	24:00	800	10:00	24:00	1,400

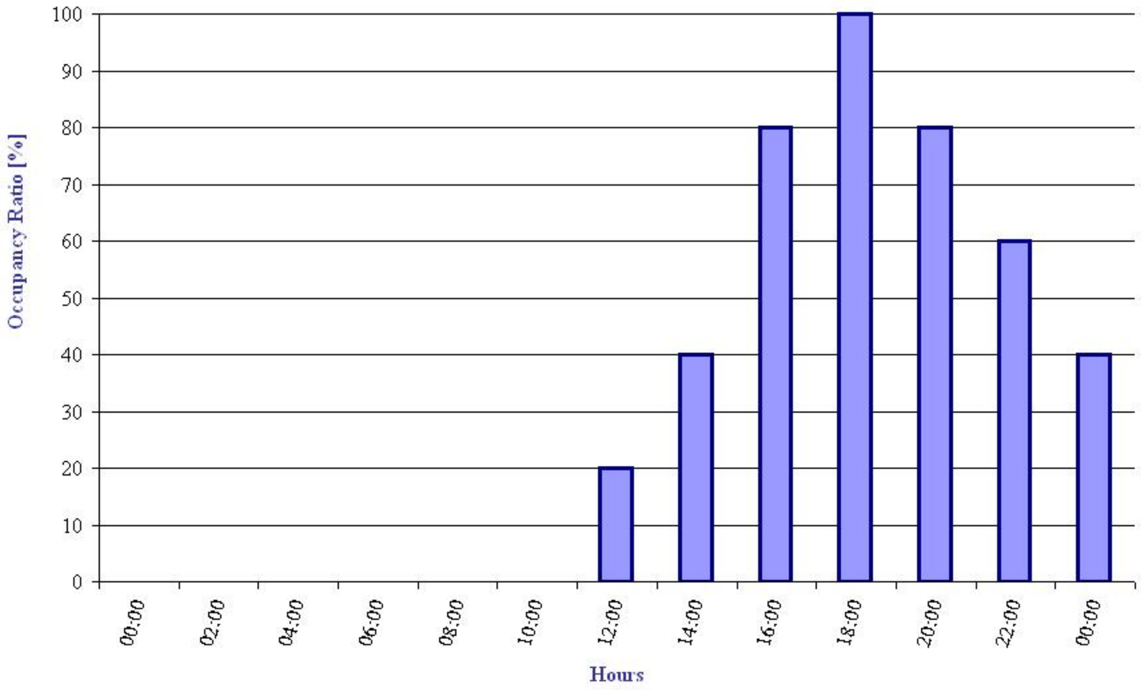


Figure 0.4. Daily building occupancy profile

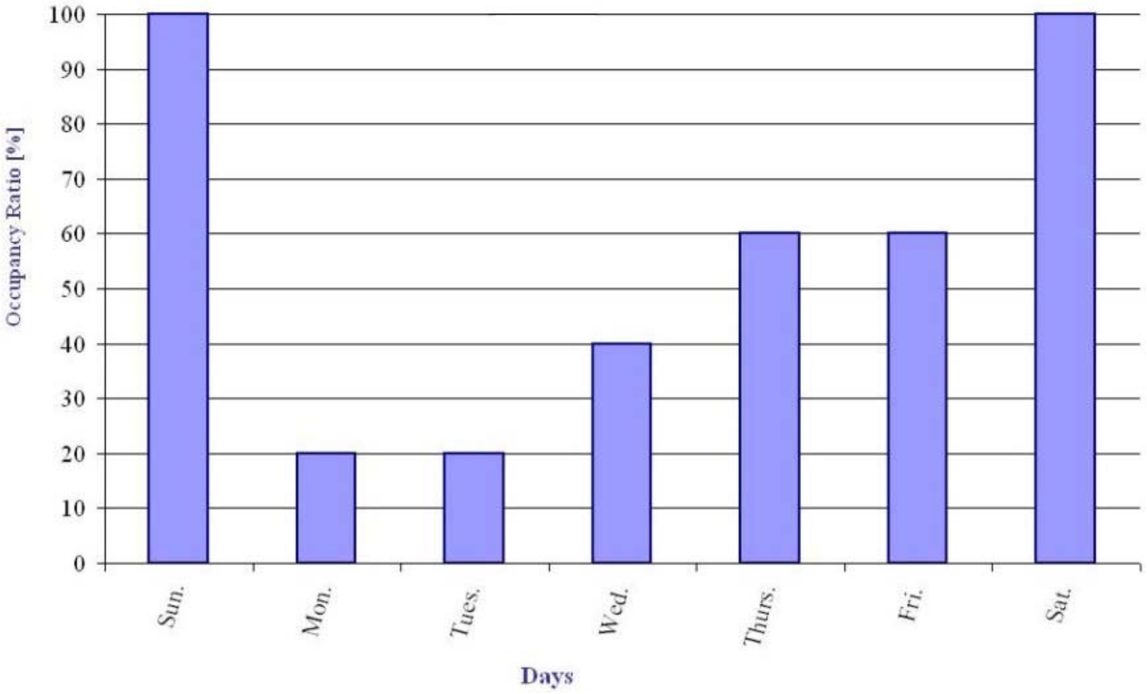


Figure 0.5. Weekly building occupancy profile

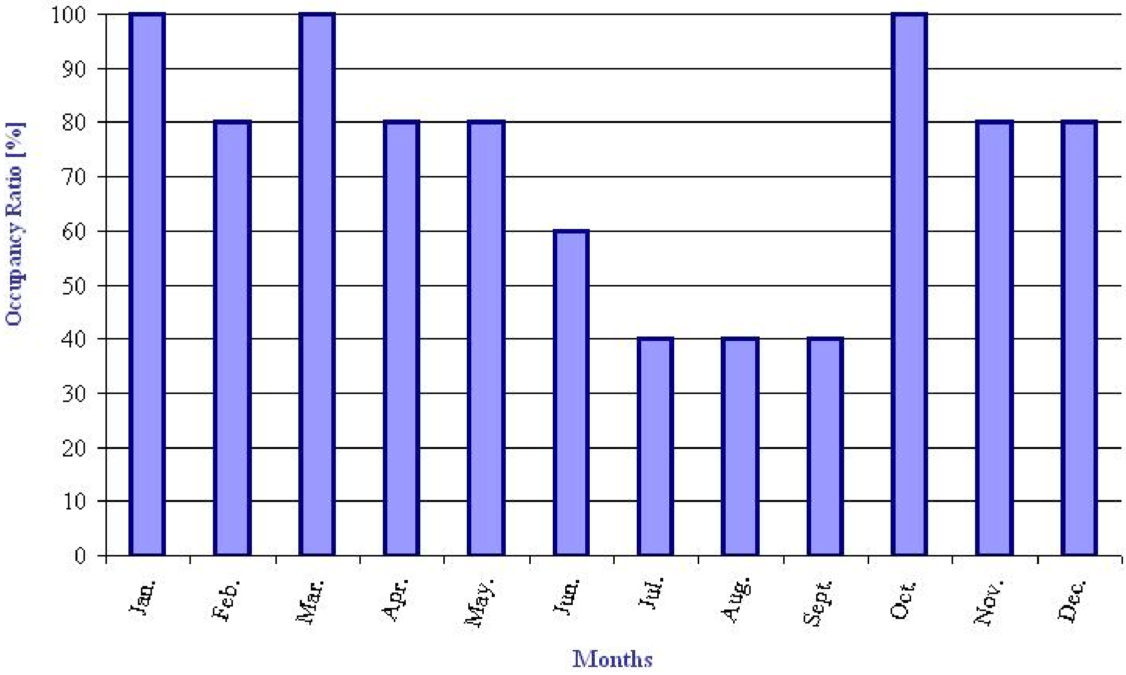


Figure 0.6. Monthly building occupancy profile

6.2.2 HVAC System Definition

The HVAC system is a constant volume, variable air temperature system. It consists of a central cooling and a heating plant and nine AHUs with flow rate from 10,000 to 54,000 m^3/h (Figure 6.7). There are two AHUs for hypermarket, two for non-food store, one for restaurant, one for café, one for offices, one for starpark and one for the main entrance. In addition to AHUs, there are 14 separate exhaust fans.

The air is conditioned by cooling and heating coils which are located inside the AHUs. Air is supplied to the conditioned space via ducting. It is returned from the space via grills and ducts back to the roof where it mixes with outdoor air before returning to the AHUs. All AHUs are located at the roof. Fresh air is supplied to the building via grills located on the AHUs. Dampers are responsible for the Outside Air (OA) / Return Air (RA) mixing ratio. café & restaurant and office AHUs works with 100% fresh air.

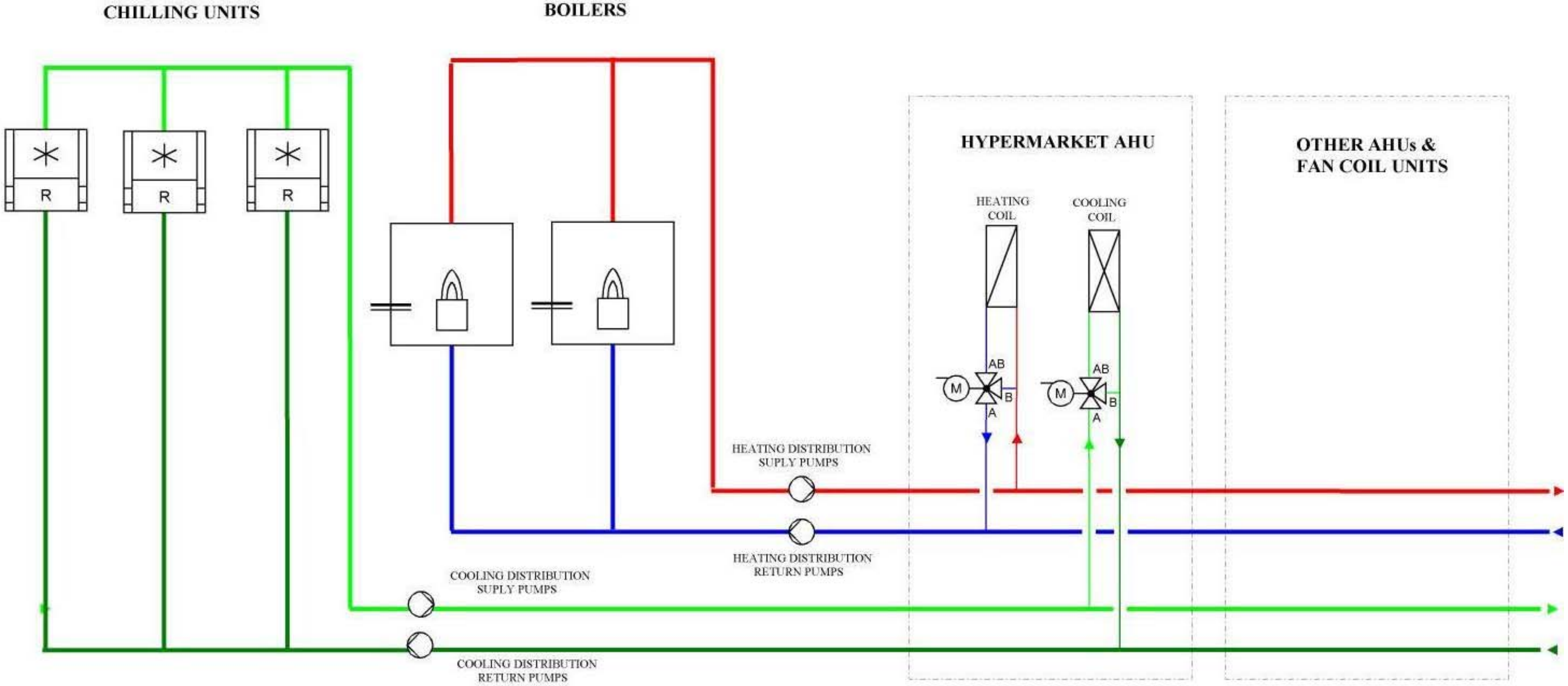


Figure 0.7. Simplified heating and cooling distribution in OSC.

The cooling of the air is done by cooling coils located inside each AHU. Digital PPI (Proportional-Proportional-Integral) cascade controllers control the water flow through the coils to maintain a set temperature at sensors located in the RA ducts. Three parallel, reciprocating air-cooled chillers supply chilled water to all the cooling coils in the AHUs. Loading and unloading of the chiller compressors maintain a set return water temperature. Each has two compressors with a rating of 37 kW per compressor and a cooling capacity of 340 kW per chiller. Eight fans condenses the refrigerant for each cooling unit located on the roof of the building. Chilling Units are good maintained and conventionally highly automated. Operation profile of the chilling unit is between 09:00 and 22:00 hours on weekdays, 09:00 and 23:00 hours on weekends, 28 weeks per year. Estimated annual hours of operation is 2674 hrs. starting from April through November. Cooling setpoint is 6-9 °C. 13 chilled water pumps are responsible for water flow through the circuits.

Similar to the cooling coils, digital PPI cascade controllers are used to control the heating water flow through coils to maintain a set temperature inside the air-conditioned areas. Two fire tube-hot water type boilers which works with LPG supplies the hot water to these coils. Boilers are maintained periodically and conventionally highly automated. Boilers are loaded and unloaded by a step controller conventionally to keep the water inside at a fixed set temperature 90-70°C. The boiler has a total heating capacity of 870 kW. 8 hot water pumps are responsible for the flow through the hot water circuit.

HVAC system is equipped with BMS which controls the temperature and time scheduled programmes. By the help of Supervisory Control and Data Acquisition (SCADA) operator can handle the HVAC system efficiently and user friendly. 9 AHUs, 2 boilers, 16 pumps, 3 chillers and 14 exhaust fans can be controlled from the BMS which is composed of the devices shown in Table 6.2.

Table 0.2. BMS equipment list

Device	Quantity
PC for SCADA	1
Control panel (DDC-PLC Unit) Compact and modular, 600 data points	8
Temperature sensor Ni 1000, -30...130 °C	22
Differential pressure switch 40-300 Pa	33
3 way control valves Valves: DN 25-150 , PN16, Drives : 0..10V continuous output	22
Frost protection monitors -5...12 °C, switch. diff. : 2..6°C	11
Damper actuator 0..10V continuous output, 15Nm with spring return	22
Humidity sensor 0..10V continuous input	11
Air quality sensor 0..10V continuous input	11

6.2.3 Energy Consumption Breakdown

Outcomes of this energy audit study which was conducted according to “Washington State University Energy Program, Energy Audit Workbook” are shown in Figures 6.8, 6.9, 6.10 and 6.11. First, general energy consumption breakdown for OCS is generated including comparison of electricity and fossil fuel consumption (Figure 6.8). This gives an idea of general energy usage of the building.

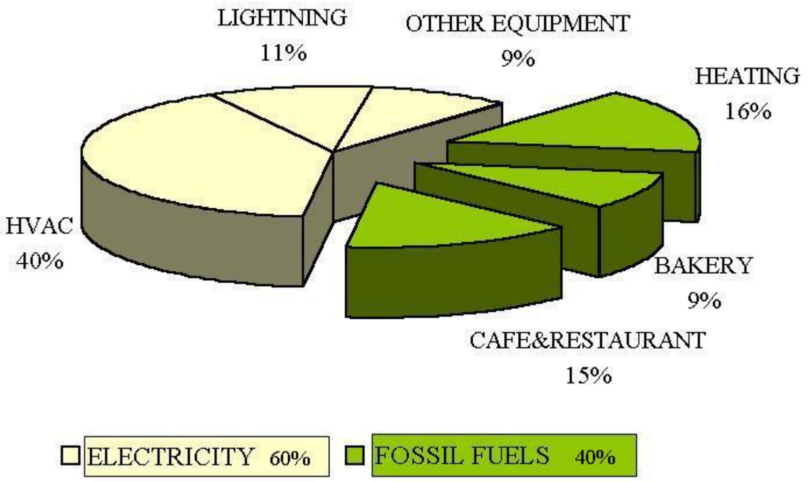


Figure 0.8. General energy consumption breakdown including electricity and fossil fuel.

To understand the seasonal energy consumption fluctuations, annual electricity & fossil fuels energy usage is plotted. (Figure 6.9.) This graph is very typical in which LPG and electricity demands are reverse. LPG demand increases in the heating season and peak demand is on January. On the other hand electricity demand increases in cooling season and peak demand is on July. Chilling units and industrial cooling has a considerable effect on electricity consumption which increases in summer season.

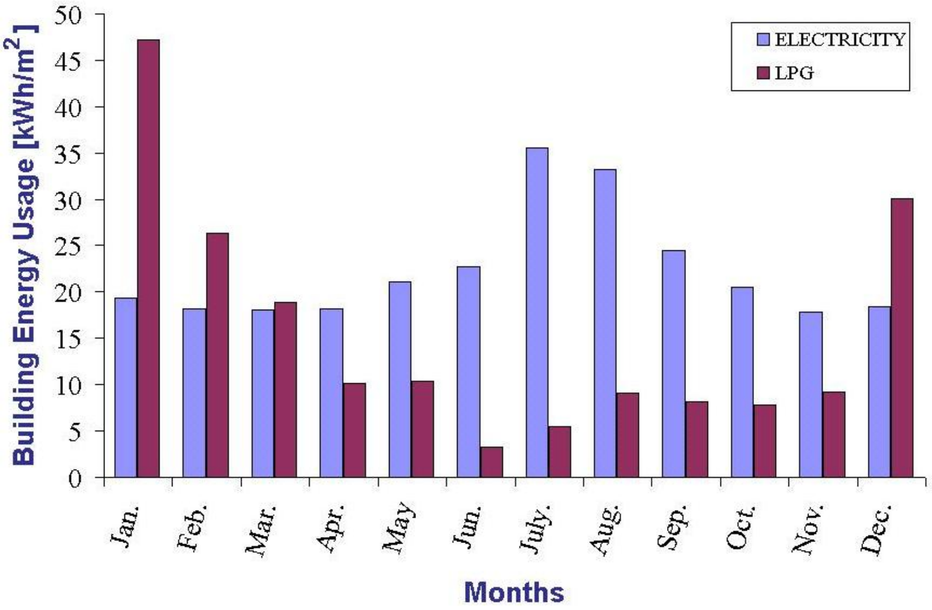


Figure 0.9. Annual building energy usage comparison for LPG and electricity

To be able to identify the largest electrical energy consumers, energy consumptions are categorized into HVAC, lightning and other equipment. (Figure 6.10) The “other equipment” category includes the electrical devices in hypermarket, non-food store, restaurant, boiler room consumers, lifts, dishwashers, computers, etc.

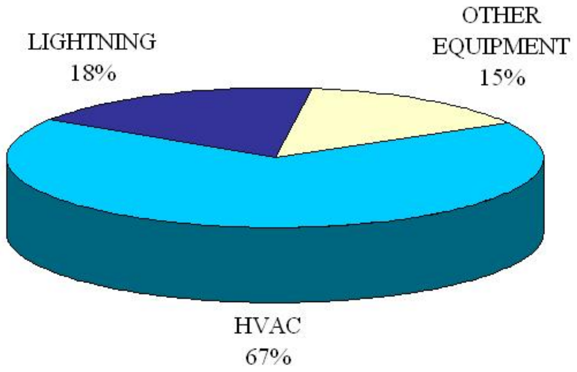


Figure 0.10. Electrical energy consumption breakdown for OSC

The HVAC equipment in OSC have the greatest energy saving potential as it is the major energy consumer. It consumes approximately 67% of the total energy consumption. The reason for this is the large internal load in the form of people in OSC, which can accommodate as many as 20,000 people/day on weekends.

HVAC energy consumption was then broken down into the various components of the HVAC system. (Figure 6.11) It is obvious that cooling is the major energy consumer in OSC with totally 73% of the energy consumption within HVAC equipment. 36% of energy consumption in HVAC equipment is for chilling units which feeds the AHU’s and FCU’s to cool the space, 37% is for industrial cooling which cools the foods to maintain fresh for a long period.

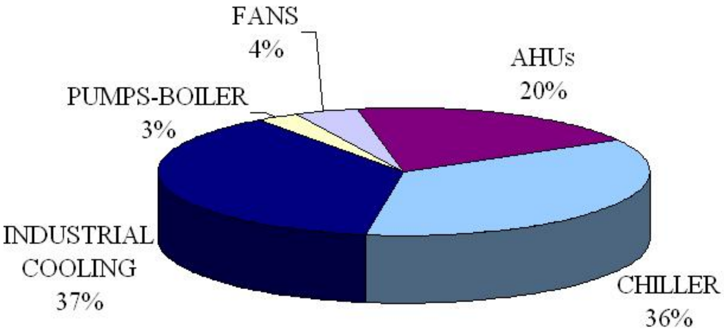


Figure 0.11. HVAC energy consumption breakdown for OSC

Control strategies for the OSC will be investigated to determine its energy savings potential. The energy audit identified the major energy consumers as well as areas where retrofits could be made to obtain energy savings.

6.2.4 Calculating the Performance Indices and Comparing to Yardsticks

Performance indices give a measure of the energy use of a building which can be compared with the yardsticks. They can indicate the potential for improvements and can be used to show progress over time. They can also allow comparisons to be made between buildings in a group or estate.

Two separate indices are calculated for the OSC; one for electricity and the other for fossil fuels. The separate indices should not be added together, because of the different cost and environmental impact of fossil fuels and electricity. The performance indices are obtained by dividing the annual building energy use by the floor area. Terms; "annual energy consumption" and "floor are information" is explained below. [21]

Annual energy consumption of a building: This is most conveniently obtained from past bills but care should be taken that the figures collected represent a full year and are not "estimated" by the utility. It may be helpful to look at more one years bills providing that there have been significant changes to the building or its use in that time. The numbers we require are the energy units consumed, not the money value.

Floor area information: The measure of floor area used to standardize energy consumption is sales area. Staff room, staff restaurant, offices, toilets, plant rooms, storage areas, etc. should completely be excluded.

6.2.4.1 The Procedure

Annual energy usage for fossil fuels and electricity has been found related to the energy audit study referenced to APPENDIX A-I-3 and A-I-4. Then these values are compared with the accepted standards referenced to United Kingdom Energy Efficiency Office.[21] In Turkey, such “Energy Consumption Yardsticks” tables are not being defined to compare the facilities. In this study OSC is categorized in “supermarkets”, thus comparison is made according to Table 6.3. In the OSC annual electricity usage is 272.7 kWh/m^2 and annual non-electricity usage (LPG) is 184.9 kWh/m^2

Looking at performance assessment table below it can be easily seen that building has *very low electricity consumption* thus performance for electricity usage is quite good. For fossil fuels building has *medium consumption* and it is within the accepted limits.

Table 0.3. Performance assessment for fossil fuels and electricity in supermarkets[21].

	Low consumption Less than		Medium consumption Between		High consumption Greater than
	→		↔		←
		Yardsticks in kWh/m^2		Yardsticks in kWh/m^2	
Fossil fuels		160		290	
Electricity		670		920	

6.2.4.2 Overall Yardsticks

Overall yardsticks based on carbon dioxide (CO_2) emissions or the cost of energy per m^2 of floor area is used to provide a single performance index. These can be used to prepare league tables which compare groups of buildings or to assess buildings which have fuel supply arrangements.

6.2.4.3 Refining the Performance Indices

To refine the performance indices of OSC, environmental and cost indices shall be added to be able to make a comparison. Effect of weather and exposure on the performance of a building, with a method to allow for these factors required. Adjustments of the "Performance Indices" for these factors produce a "Normalized Performance Indices". For many purposes, the effect of these factors on performance indices is small enough to be ignored.

6.2.4.4 Overall Performance Indices

Overall performance indices provide a single measure of building performance, and can be expressed in terms of carbon dioxide (CO_2) emissions or energy costs. Overall energy indices are useful for comparing a stock of buildings, however, separate fossil fuel and electricity performance indices are more useful to assist in deciding a course of action.

To calculate overall performance indices annual energy use indices are used which were obtained from the energy audit study referenced to APPENDIX A-I-3 and A-I-4. Conversion factors for the fuels some which are given in Table 6.4, Table 6.5 are defined by United Kingdom Energy Efficiency Office [21]. The calculation procedure is to enter the kWh/m^2 for the related source, and multiply by the relevant conversion factors to get either the kg of CO_2 per m^2 or the cost per m^2.

Table 0.4. CO_2 Performance Index Calculation [21].

	Annual energy use kWh/m²	CO_2 conversion factors kg/kWh	Annual CO_2 emissions kg/m²
Gas	184.9	x 0.20	36.98
Oil	0	x 0.29	0
Coal	0	x 0.32	0
Electricity	272.7	x 0.70	190.89
Total energy cost per m²			227.87

Table 0.5. Cost Performance Index Calculation [21].

	Annual energy use kWh/m²	Cost conversion factors \$/kWh*	Annual cost \$/m²
Gas	184.9	x 0.04	7.39
Oil	0	x 0.012	0
Coal	0	x 0.009	0
Electricity	272.7	x 0.095	25.90
Total energy cost per m²			33.29

* Annual mean values for the year 2002 in Turkey

The conversion factors for the CO_2 emissions are typical values at the year 1993. Cost conversion factors are typical values for the year 2002 as billed to OSC. Currency is taken as USD(\$) to reduce the effects of inflation.

Overall assessment for CO_2 emissions and energy costs shall be made by the help of the Tables 6.6 and 6.7.

Table 0.6. CO_2 Performance Assessment for Buildings with Fossil Fuel an Electricity Supply [21].

	Low Emission Less than	Medium Emission Between	High Emission Greater than
	→	↔	←
	Yardsticks in kg CO_2/m²		Yardsticks in kg CO_2/m²
Supermarkets	500		700

Table 0.7. Cost Performance Assessment for Buildings with Fossil Fuel an Electricity Supply [21].

	Low Cost Less than	Medium Cost Between	High Cost Greater than
	→	↔	←
	Yardsticks in \$/m²		Yardsticks in \$/m²
Supermarkets	78		108

6.2.4.4.1 Effects of Weather on Energy Use

Weather changes from year to year for a given site cause variations in fossil/heating energy use of typically ± 5% from the average values and ± 10% in more extreme years.

Weather differences across the country cause variation in heating requirements of typically ±10% from the average values and ±20% in more extreme areas.

The effect on electricity use will be small unless electricity is used for space heating, or in air conditioned buildings where the cooling energy will be higher during a warm summer.

6.2.4.4.2 Effects of Exposure on Energy Use

If a building is very exposed (on an exposed hill for example), heating energy increases by 5-10% and likewise a completely protected building may use 5-10% less. In many cases steps will have been taken on exposed buildings to improve draught sealing which will offset the increase. Electricity use is largely unaffected except in electrically heated buildings. Exposure factors can be defined by the help of Table 6.8.

Table 0.8. Exposure Factor [21].

Sheltered: The building is in a built-up area with other buildings of similar or greater height surrounding it. This would apply to most city center locations	1.1
Normal: The building is on level ground in urban or rural surroundings. It would be usual to have some trees or adjacent buildings.	1.0
Exposed: Coastal and hilly sites with little or no adjacent screening	0.9

6.2.4.5 Normalized Performance Indices

It is possible to adjust (normalize) performance indices for weather and exposure (Table 6.9), but care is needed as incorrectly applied adjustments, or adjustments that are too simplistic, may introduce larger errors than the typical variations discussed above. For example, the effect of extended hours of use on energy consumption can easily be exaggerated, making the building performance seem better than is really the case.

Also a normalized performance index is a better measure of a building's efficiency than unnormalized index; the latter shows the building's actual performance. So a building with a low normalized performance index, but a high performance index before adjustment, is efficient, but since it is still a high user of energy, it may well offer good opportunities for cost effective energy saving [21].

Performance indices shall be summarized as follows:

- Simple performance indices are for initial energy assessments. Separate performance indices are calculated, one for fossil fuels and one for electricity use, and no adjustments made.
- Overall performance indices, based on carbon dioxide (CO_2) or cost, are normally used when the energy supply arrangement is not typical or when a number of buildings are to be compared. Also, you may want to know the cost or the CO_2 performance for a single store.
- Normalized performance indices are used when more sensitive comparisons are required and the effect of factors such as exposure and weather become significant. But if you choose to normalize, be aware of introducing errors.

Table 0.9. Normalized Performance Indices Calculation [21].

	Gas	Fossil fuel Oil	Other		Total of Fossil Fuels	Total of Electricity
Total energy consumption (kWh)	2,958,216	0	0	(A)	2,958,216	4,363,104
Space heating energy (kWh)	1,183,286	0	0	*(B)	1,183,286	2,923,279
Non space heating energy (kWh)	1,774,929	0	0	A-B = (C)	1,774,929	1,439,825
Find the degree days for the energy data year				*(D)	1223	
Weather correction factor = 2462 / D =				(E)	2.013	
Obtain Exposure factor for heating energy use form Table 6.8				*(F)	0.9	
Annual heating energy use for standard conditions				BxExF= (G)	2,143,759	5,296,104
Normalized energy use = C + G =				(H)	3,918,688	6,735,929
Find floor area				m² (J)	16,000	16,000
Find the Normalized Performance Indices = H / J =				kWh/m² (K)	245	421

6.3 Action Plan

Scope of the action plan is based on revisions of HVAC control strategies and redefining the control parameters, since 67% of the total building energy consumption is consumed by the HVAC system. This means that the biggest potential for building energy saving lies in HVAC system retrofit options. Actual control strategies are analyzed and compared with values generated from the energy audit study. The importance of cooling is understood but no major changes were made in cooling control strategy. Chillers are well controlled conventionally and there is no need to define extra strategy for energy saving for cooling. So AHUs are focused as the second major energy consumers in HVAC group. To specialize and to start on experimental study the major consumer from the AHU's are determined.

Action plan (Figure 6.1) was originated and realized by the help of BMS. Advantages of the BMS are used without making any investment. This study should be named as tuning parameters and redefining the control strategies. In the existing system, control strategies are not clearly defined and control parameters are not site synchronized.

Regarding to the survey on historical database of the SCADA (novaPro), fluctuations from the setpoints are observed and retrofit study is focused on the hypermarket and non-food store AHUs. These AHUs are the major energy consumers comparing with the other AHUs and setpoint deviations are very high as found from the survey carried on historical database and trends. These two air handling units are quite important because they are directly related to clients comfort.

Aim of the action plan is to generate new start/stop times due to occupancy profile (not depending upon the operator), to implement control principles such as night purge, night cycle and free outside cooling strategies and to tune PPI cascade controller for the sequence control for heating and cooling.

6.4 Site Study

6.4.1 AHU System Description

Hypermarket and non-food store AHUs are typically the same. But their heating-cooling capacities and fan powers are different (Table 6.10). Both of them uses RA to mix with OA for energy conservation. Air enters to the AHU from OA damper and if needed mixed by RA. Then air passes through a filter and then heating coil and cooling coil simultaneously. SA fan forces the air to ventilate through the conditioned space by diffusers. Air is aspirated from space by RA fan and if no mixing of air needed it exhaust by the Exhaust Air (EA) damper.

Table 0.10. Power consumptions of AHUs

Zone	Cooling coil [kW] 7/12 °C	Heating coil[kW] 90/70 °C	Fan power [kW]
Hypermarket AHU	506.7	274,2	45
Non-food store AHU	400.1	295,4	45

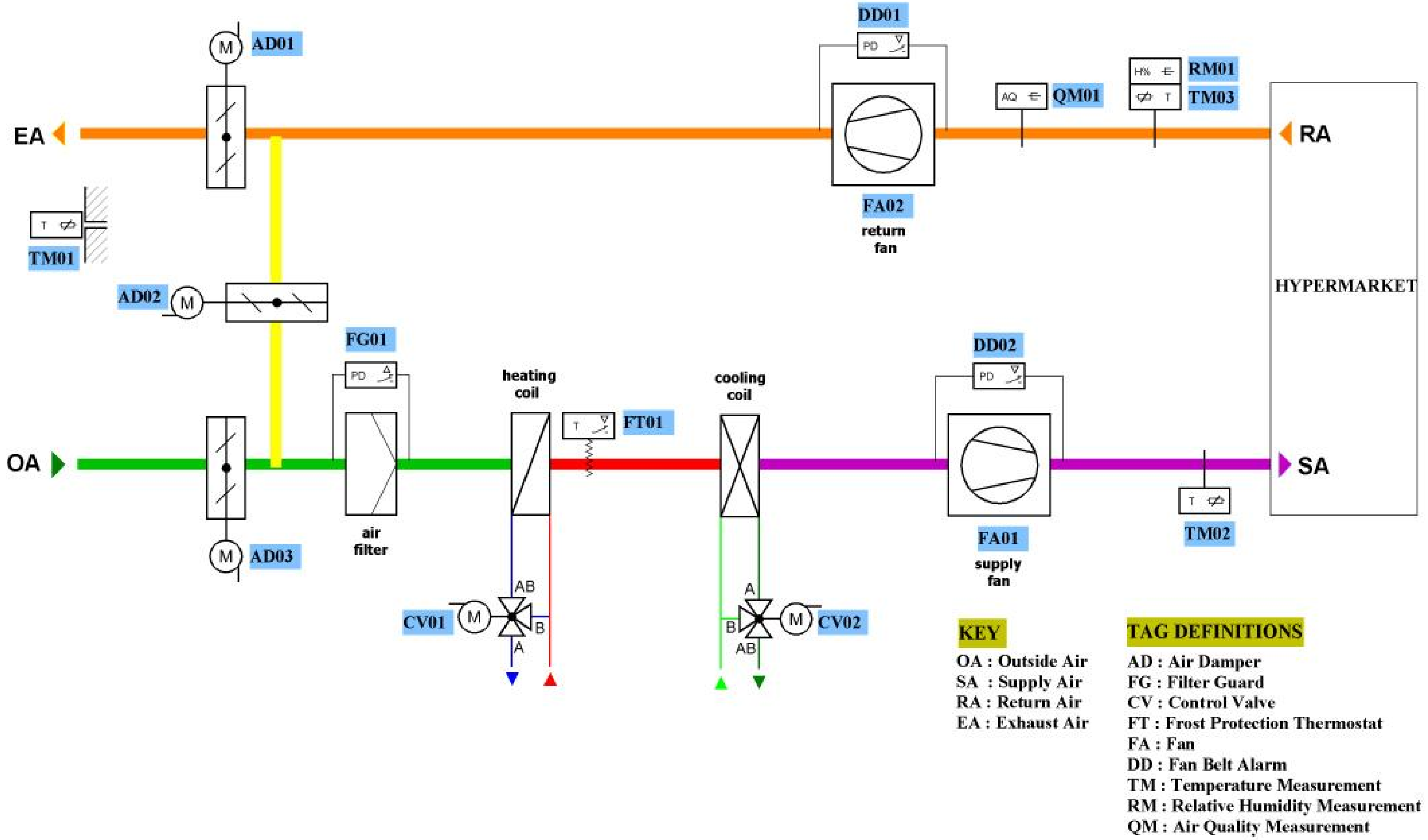


Figure 0.12. Flow diagram of AHU

6.4.2 Current Control Scenario

Supply and return fans can directly be switched on from SCADA if they are in automatic position. These fans have interlocks in case of failure of operation which can be observed from SCADA. AHU operates as per the sequence ‘heating coil – air dampers – cooling coil’. The parts of the sequence are formed in the controller. The measurement for the room-air temperature is taken in the RA duct. All control loops activate when supply and return fans status are on. OA and EA dampers close and RA damper opens when fans are off and modulate for temperature control when fan is on. Also heating and cooling valves closes when fans are off.

P+PI cascade and a PI single controller is used. The supply air (SA) temperature is measured by sensor TM02, and the room-air temperature by the RA sensor TM03. The SA temperature is controlled by the PI auxiliary controller (control signals to CV01, CV02, AD01,AD02 and AD03). The setpoint for the PI control loop is formed by the P main controller, with the RA temperature as the controlled variable. The setpoint is lowered as the RA temperature rises, and raised as it falls. The control deviation is compensated for by adjusting the control signals to CV01, CV02, AD01, AD02 and AD03. The minimum and maximum SA temperatures are given in the parameters of the blocks. Reversal of the direction of operation for the control signal to AD01-AD02 and AD03 for the dampers for heating-cooling operation in accordance with the difference between the OA temperature and the RA temperature.

The minimum position of the fresh-air damper is set by the user interface from SCADA view or from FBD (Function Block Diagram). FBD is a tool to parameterize and create control logic. Return fan shall operate anytime the supply fan proves flow (via a current sensing relay). The ventilator's fan-belt and the filter's clogging level are monitored by differential-pressure switches. The frost-protection functions are triggered by a frost-protection monitor which opens the heating coil in case of activation and stops supply and return fans.

6.4.3 Implemented Control Strategies

To understand the implemented strategies and current control loops, control block diagram of these two AHUs are plotted and can be seen in Figure 6.13. Looking at this diagram we can see overall control process on AHU and implemented strategies such as Optimum start-stop, FOC, night purge and night cycle.

Optimum start-stop strategy calculates a lead time to turn on or off heating or cooling equipment at the optimum time to bring temperatures to proper level at the time of occupancy. This strategy adjusts AHU stop time to allow stored energy to maintain the comfort level to the end of the occupancy period. Optimum start-stop time delays are shown on figure below. During the optimum start period AD01 and AD03 are fully closed because of non-occupancy.

Free outside cooling (FOC) can be enabled by the operator from the SCADA. FOC controls the cooling of the space by utilizing the low temperature at night. Significantly less cooling energy needs to be expended for hypermarket and non-food store that are pre-cooled this way. Every evening at 18:00, the strategy saves OA temperature from TM01 and RA from TM03. The approximate maximum temperature is reached at about this time in the summer. If OA temperature is less then 25°C or if RA temperature is less than 22°C this block de-activates itself which guarantees to work in cooling season. One other interlock for the block is comparison of RA and OA temperatures. If (RA temperature) – (OA temperature) < 2°C module de-activates. If RA temperature is less than 20°C module is also de-activates. Whenever the module activates it sends a signal to AD01 and AD03 to open 100%.

Night Cycle strategy activates only in unoccupied periods and maintains a low temperature limit in the heating season. If space temperature is less than 18°C after midnight, strategy activates and heating start-stops periodically till the optimum start time. The AHU starts at 12:00 and stops 30 minutes later. After one hour stop period it starts again for 30 minutes till the optimum start time.

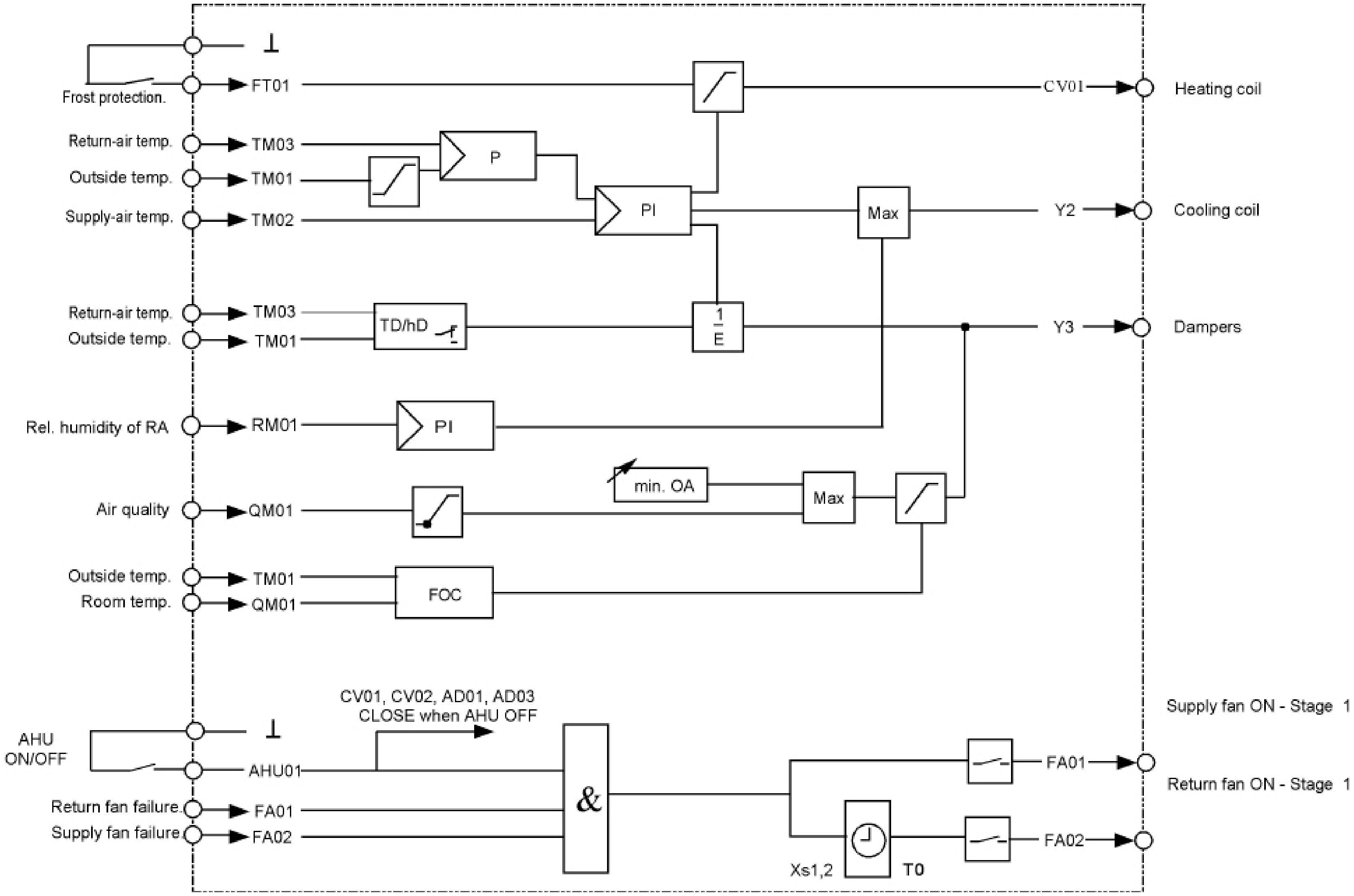


Figure 0.13. Automatic control block diagram of AHU

Night Purge strategy enables to use cool, night outdoor air to pre-cool the building before the mechanical cooling is turned on. To activate the strategy, cooling season shall be selected and RA temperature must be over 24°C. Also, OA dew point shall be less than 16°C.

6.4.4 Tuning control parameters

The efficiency of a control scheme to reduce energy use and to maintain comfort largely depends on proper controller tuning. Tuning can be performed manually, automatically with auto-tuners which have a special feature to be turned on and off by an operator, or automatically with adaptive controllers which are self-tuning. Currently, most commercial and institutional buildings are equipped with PID (proportional integral derivative) controllers to keep variables, such as temperature and pressure, at predefined setpoints which are manually tuned or with auto-tuners. In these cases, interactions between the different control loops of the system can occur. This results in one loop being tuned to the detriment of another.

The systematic tuning of controllers improves the performance of all controls and is particularly important for digital control. First, the controlled process should be controlled manually between various setpoints to evaluate the following questions:

- Is the process noisy (rapid fluctuations in controlled variable)?
- Is there appreciable hysteresis (backlash) in the actuator?
- How easy (or difficult) is it to maintain and change setpoint?
- In which operating region is the process most sensitive (highest gain)?

If the process cannot be controlled manually, the reason should be identified and corrected before tuning the controller. Tuning selects control parameters that determine the steady-state and transient characteristics of the control system. HVAC processes are nonlinear, and characteristics change on a seasonal basis. Controllers tuned under one operating condition may become unstable as conditions change. A well tuned controller will (1) minimize the steady-state error for setpoint, (2) respond quickly to disturbances, and (3) remain stable under all operating conditions. Tuning of proportional controller is a compromise between minimizing steady-state error and maintaining margins of stability. Proportional plus integral (PI) control minimizes this compromise because the integral action reduces steady-state error, while the proportional term determines the controller's response to disturbances [22].

In the case study of OSC, tuning control parameters of the hypermarket and non-food store AHU is focused. The process was noisy that fluctuations from the setpoints are high. Temperature control is made by PPI cascade controller. P controller calculates a set point for SA and SA air temperature is controlled by the PI auxiliary controller (control signals to CV01, CV02, AD01,AD02 and AD03). Minimum and maximum limits for the SA is determined as 16°C and 36 °C. The slope for the P main controller is 10. The setpoint for the PI control loop is formed by the P main controller, with the RA temperature as the controlled variable. The setpoint is lowered as the RA temperature rises, and raised as it falls. The control deviation is compensated for by adjusting the control signals to CV01, CV02, AD01, AD02 and AD03. Proportional band for the PI auxiliary controller is 12 and integral time is 180 seconds. Reversal of the direction of operation of the control signal for AD01-AD02 and AD03 is determined by heating/cooling selector which depends on OA and RA temperature. Output signal from the PPI controller is sequenced heating coil-air dampers-cooling coil as shown in FBD referenced to APPENDIX B

Humidity control is made by a PI block which is used only to maintain the humidity in maximum limit. There is no humidifier in the process so only a drying by cooling coil is defined.

Air quality control is made by a Curve-4 block. Whenever the air quality is poor the OA damper opens to increase the quality of the conditioned space.

Chapter 7

RESULTS & DISCUSSIONS

Case study which was carried out in OSC is a combined study in which the energy audit of the building is done and also some retrofit studies are carried on. This idea is originated by using more functions on HVAC control system. To implement strategies on HVAC control system, energy audit was generated. This was very helpful deciding where to focus our retrofit study. Some retrofit options are implemented such as optimum start-stop, FOC and night purge. Results of energy consumptions and savings are tabulated on Table 6.11.

Table 0.1. Summary of energy and environmental data for hypermarket AHU in summer case.

Estimated daily consumptions	Without any strategy	Optimum Start-stop	FOC	Night Purge
Return Fan (kWh)	630	462	630	756
Supply Fan (kWh)	630	462	630	756
Total Fan (kWh)	1,260	924	1,260	1,512
% Saving	-	26.6	-	-20
Cooling Coil (MJ)*	25,537	18,715	22,454	23,713
% Saving	-	26.7	12	7.1
Overall electricity usage(kWh)	2,125	1558	2,020	2,302
% Saving	-	26.6	4.9	-8.32
Average CO_2 emission (kg)**	1,487	1,090	1,414	1,611

* COP for the chilling unit is 4.1, average valve position: 50%

** CO2 conversion factors; Electricity :0.7 kg/kWh

As it can be seen from Table 6.11 some strategies may have disadvantages while some have high energy saving potentials. For example night purge strategy consumes extra fan power to cool down the building in the midnight, but delay of starting the chilling units brings advantage on energy usage. FOC has no effect on fan power consumption but should have great potential in spring or autumn. This strategy activates only in occupancy periods.

Optimum start-stop strategy is very important because it saves energy independent to seasonal changes. In this study effect of night cycle strategy and heating coil energy consumption values are not considered. These values can only be considered in the heating season.

There are two important results for the study carried out in OSC. Comparing with the yardsticks, the performance of the building is very good for electricity consumption and within the accepted limits for fossil fuel (LPG) consumption. Other result is energy savings obtained by the retrofit studies which was carried out in the hypermarket AHU. Approximate saving for electricity usage in summer case is 22%. But studies should carry on for every season and for long terms. Current results should not be a realistic measure of implemented HVAC control strategies. For other AHUs and HVAC devices, such control strategies should be implemented. This case study is done without making any investment to the building.

OSC has an ongoing non-systematic energy management programme. Many energy data were recorded but evaluation of these values were not considered systematically till this study. Case study in the OSC is generated from the data of year 2002. Similar study should be carried for the year 2003 and energy data should be evaluated and precautions should be taken for the significant energy consumers. As a suggestion, a certified energy manager should investigate the potentials for energy savings and should observe the energy audit continuously.

Current BMS in the OSC should be a much more effective tool for energy management. It needs more engineering and team-work to use more capacity of the system. For instance, working hours of the fans, pumps etc. should be calculated and maintenance schedules should be decided automatically. Alarm reports and trends should be printed out regularly to understand weak parts of the HVAC system. Historical database should be evaluated by an external programme such as MS EXCEL.

To assess the different kinds of buildings “Energy Consumption Yardsticks” tables should be created for Turkey’s conditions. Chamber of Mechanical Engineers should constitute a working group to form this yardstick tables.

Chapter 8

CONCLUSIONS

This study proves that efficient HVAC control is one of the most cost-effective options to improve the energy efficiency of a building. The effect of changing the control strategy is usually difficult to predict so every strategy shall be tested for every season. Also the success of implementing efficient energy management and HVAC control is coupled with understanding the performance of mechanical and control systems.

To initialize a case study in OSC, a methodology is developed. This methodology has four phases: 1- *Definition* of building characteristics and HVAC system by conducting an energy audit. 2- *Planning* of a methodology and an action plan, 3- *Implementation* of the site studies. 4- *Completion* by comparing the results with the proceeding values.

To start a retrofit study in the OSC, energy audit study was carried out and potentials for energy savings are investigated. Characteristics of the building and its HVAC system understood. Within the energy audit study, performance of the building is investigated and as a result building performance on LPG usage is *medium consumption*. electricity usage is in *low consumption* level achieved.

Action plan was defined and hypermarket and non-food store AHUs are focused. Control scenarios of these AHUs are deeply investigated revisions are made. Some HVAC control strategies such as optimum start-stop, night purge, night cycle are implemented. Control loops and parameters are tuned due to characteristics of the building. Energy savings obtained by these retrofit studies which was carried out in the hypermarket AHU is approximately 22% in summer case.

The importance of BMS and HVAC control strategies are understood with this study. Authors wishes that this study leads to convince the building owners to give importance to energy matters and HVAC control.

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APPENDIX A

ENERGY AUDIT STUDY

Washington State University Energy Program
Energy Audit Workbook*

WSUEEP98027

Table of Contents

Energy Audit Instructions

I. AUDIT FORMS

*Note: This work book was originally prepared by the Washington State Energy Office, which is now known as the Washington State University Energy Program.

1. Building Information

Name of Institution **ÖZDİLEK ALIŞVERİŞ MERKEZLERİ VE TEKSTİL SANAYİ A.Ş.**	Address **İNCİRALTI MAH. 10. SOK. NO:67** **BALÇOVA / İZMİR**
Owner, if other than Institution **ÖZDİLEK A.Ş.**	Address **YENİYALOVA YOLU 4. KM BURSA**
Name of Building **ÖZDİLEK ALIŞVERİŞ MERKEZİ** İNCİRALTI	Building #
Address (Street or P.O. Box) **İNCİRALTI MAH. 10. SOK. NO:67**	City, State, Zip **BALÇOVA / İZMİR**
Date of Audit **02.10.2002**	Type of Institution Public____Private Non-Profit ____ Other _**SHOPPING CENTER**___
Building Manager (administrator responsible for bldg.) **Mr. HAMZA ARI**	Bldg. Mgr.'s Phone **+ 90 232 2781200 - 2030/2530**
Energy Management Coordinator (EMC) or Monitor **Mr. HAMZA ARI**	EMC's Phone **+ 90 232 2781200 - 2030/2530**
Person Completing this Audit (include Cert. #) **ÇAĞLAR SELÇUK CANBAY**	Phone **+ 90 232 4698104**

Building Type and Category

School
__Element.
__Second.
__Comm.Coll.
__Coll./Univ.
__Voc. Tech. Ctr.
__Other, Specify
____

Hospital
__General
__Psychiatric
__Other, Specify
____

Government
__Federal
__State
__City/County
__Special Dist.
__Indian Tribe

Public Care
__Nurs. Home
__Long-term care
__Rehab. Center
__Orphanage
__Public Health
__Res. Child Care
__ Other, Specify
____

Date of construction, If known **15.11.2001**

Building Use
_X_Office
_X_Storage
____Library
_X_Services
____Police Station
____Fire Station
___Dormitory
___Prisoner Detention
_X_Other, Specify
SHOPPING CENTER

Original Architects (if known) **Mr. BARBAROS SAĞDIÇ**	Original Engineers (if known) -----
Building Modifications or Changes In Use Anticipated in the next 15 yrs:	Remaining Useful life of the building: __**100**__Years
Does the Institution Have an ongoing energy management program?	_X_Yes ___No

Previous Energy Audits Completed? (if yes, give dates)_X_Yes __No
Dates ____**EVERY MONTH**_______________ ______________ ______________

Previous Architectural/Engineering Studies Undertaken? (if Yes, specify) ___Yes _X_No

Name of Electric Utility **TEDAŞ A.Ş.**	Is this building on the National Historic Preservation Register? __Yes _X_No

2. Building Characteristics

a. **Gross Floor Area**: _**20,000**_ Gross Sq.m. x Ceiling Height __**3-6**__ m. = volume **115,000**_Cu.m.
b. **Conditioned Floor Area**: __**20,000**_ (if different that gross floor area)
c. **Total door Area**: __**252**______ Sq.m Glass doors __**40**__sq.m Wood doors _**150**_sq.m.
Metal doors __**30**___ sq.m. Garage doors __**32**_ sq.m
d. **Total Exterior Glass Area**: ___**2,660**____sq.m Single Panes ___**0**____sq.m. Double panes _**2,660**_sq.m.

	North	**South**	**East**	**West**
Total Area	___**792**__sqm	____**0** __sqm	__ **480**__sqm	____**0** ___sqm
Single Pane	________sqm	_________sqm	________sqm	_________sqm
Double Pane	___**792**__sqm	____**0** __sqm	__ **480**__sqm	____**0** ___sqm

e. **Total Exterior Wall Area**: ____**1272**____ sqm Material: [ ]Masonry [ ]Wood
[ ]Concrete [ ]Stucco [**X**]Other
f. **Total Roof Area**: ___**9,840**_____sqm Condition: [ ]Good [**X**]Fair [ ]Poor
g. **Insulation Type**: **Polyurethane** Roof **Ytong & Aluminum** Wall **Packaged membrane** Floor
h. **Insulation Thickness**: _**200mm**____Roof ____________Wall ___________Floor
i. **Metering**: Is this building individually metered for electricity? [**X**]Yes [ ]No
Is this building individually metered for natural gas? [**X**]Yes [ ]No
Is this building on a control boiler system with other buildings? [ ]Yes [**X**]No

3. Annual Electric Use And Cost

Include Electrical Demand, if applicable

Building **ÖZDİLEK AVM**	Address **İNCİRALTI MAH. 10. SOK. NO:67 BALÇOVA / İZMİR**	Year of Record From **2002** / To **2002**
Account Number	Meter Number	Utility **SHOPPING CENTER**
Maximum kW Demand W/O charge	Minimum Power Factor W/O charge	Building size (m^2)**** **16,000**

1	2	3	4	5	6	7	8	9	10
Meter Read Date From	 To	KWh* Used	KWh/gross m^2. **	Annual (EUI) BTU/sqft (000)	Energy Cost $	KW-KVA Demand	Fixed Service Cost	P.F. * and Demand Cost***	Total Cost $
1st ,Jan.	**31st ,Jan.**	**310,524**	**19.40**		**0.10081**				**31,303**
1st ,Feb.	**31st ,Feb.**	**290,791**	**18.17**		**0.09750**				**28,352**
1st ,Mar.	**31st ,Mar.**	**289,648**	**18.10**		**0.10187**				**29,506**
1st ,Apr.	**31st ,Apr.**	**290,225**	**18.13**		**0.10533**				**30,569**
1st ,May	**31st ,May**	**337,383**	**21.08**		**0.10311**				**34,787**
1st ,Jun.	**31st ,Jun.**	**443,223**	**27.70**		**0.08845**				**39,203**
1st ,July.	**31st ,July.**	**569,635**	**35.60**		**0.08516**				**48,510**
1st ,Aug.	**31st ,Aug.**	**530,600**	**33.16**		**0.08826**				**46,830**
1st ,Sep.	**31st ,Sep.**	**391,293**	**24.45**		**0.08954**				**35,036**
1st ,Oct.	**31st ,Oct.**	**329,222**	**20.57**		**0.09138**				**30,084**
1st ,Nov.	**31st ,Nov.**	**284,854**	**17.80**		**0.09435**				**26,876**
1st ,Dec.	**31st ,Dec.**	**295,706**	**18.48**		**0.09924**				**29,346**
TOTAL		**4,363,104**	**272.7**						**410,402**

Comments:
Conversion: 3413 BTU/kWh
*KW – Kilowatts, KVA – Kilo-Volt-ampere, KWH – Kilowatt hour, P.F. – Power Factor
**Total annual kWh divided by the building's gross sq. m.
***If demand and/or power factor are metered and billed, energy cost here.
****Offices, staff rooms, toilets, storage areas are excluded while calculating the building size (m^2)

4. Annual Non-Electric Energy Use and Cost

Photo copy this form for additional fuel types

Building **ÖZDİLEK AVM**	Address	Year of Record From 2002 To 2002
Account Number	Meter Number	Utiilty
Building Size (m^2)* **16,000**	Fuel Type **LPG**	Specify Units

Billing Period		Fuel consumption [kg]	Conversion Factor**	kWh	Annual kWh/m^2	Cost $
From	To					
1st ,Jan.	**31st ,Jan.**	**58,665**	**12.87**	**755,014**	**47.19**	**25,258**
1st ,Feb.	**31st ,Feb.**	**32,788**	**12.87**	**421,981**	**26.37**	**14,371**
1st ,Mar.	**31st ,Mar.**	**22,213**	**12.87**	**285,881**	**17.87**	**11,468**
1st ,Apr.	**31st ,Apr.**	**12,631**	**12.87**	**162,560**	**10.16**	**6,939**
1st ,May	**31st ,May**	**12,828**	**12.87**	**165,560**	**10.32**	**6,993**
1st ,Jun.	**31st Jun.**	**3,990**	**12.87**	**51,353**	**3.21**	**1,933**
1st ,July.	**31st July.**	**6,770**	**12.87**	**87,129**	**5.45**	**3,228**
1st ,Aug.	**31st Aug.**	**11,345**	**12.87**	**146,005**	**9.13**	**5,659**
1st ,Sep.	**31st Sep.**	**10,128**	**12.87**	**130,347**	**8.15**	**5,159**
1st ,Oct.	**31st ,Oct.**	**9,665**	**12.87**	**124,390**	**7.77**	**5,601**
1st ,Nov.	**31st Nov.**	**11,388**	**12.87**	**146,568**	**9.16**	**7,280**
1st ,Dec.	**31st Dec.**	**37,443**	**12.87**	**481,895**	**30.12**	**26,018**
TOTAL			**12.87**	**2,958,216**	**184.89**	**119,906**

***Conversion Factors**

Natural Gas	100,000 Btu/therm
Natural Gas	1,030 Btu/cubic feet
Liquified Petroleum	(LP bottled gas) 95475 Btu/gallon
Kerosene	134,000 Btu/gallon
Distillate Fuel Oil	138,690 Btu/gallon
Residual Fuel Oil	149,690 Btu/gallon
Coal	24.5 million Btu per Standard short ton
Wood	8,680 Btu/pound
Steam	970 Btu/pound
Other	Consult standard Engineering Reference Manual
Natural Gas	12.428 kWh/kg

Comments: *Offices, staff rooms, toilets, storage areas are excluded while calculating the building size (m^2)

**According to DIN 51622, Lower heating value Hu : 12,87 kWh/kg

5. Heating Plant

	PRIMARY	SECONDARY1	SECONDARY2
(A) System Type Code	**3**		
How many each type?	**2**		
Rated Output Capacity	**870 kW**		
(B) Energy Source Code	**2**		
(C) Maintenance Code	**1**		
(D) Control Code	**3**		

(A)System Type Code

1. Fire tube-Steam
2. Water tube-steam
3. Fire tube-hot water
4. Water tube-hot water
5. Electric Resistance
6. Heat pump with aux. Elec.heat
7. Purchased steam
8. Other (explain)

(B)Energy Source

1. Natural Gas
2. LP Gas
3. #2 Fuel Oil
4. #4 Fuel Oil
5. #6 Fuel Oil
6. Electricity
7. Coal
8. Wood
9. Solar
10. Purchased Steam

©Maintenance Code

1. Good
2. Average
3. Fair
4. Poor

(D)Control Code

1. Manual
2. Somewhat automated
3. Highly automated

Operation Profile:

____**24**____hrs/weekday ______**24**____hrs/Sat. ______**24**_____hrs/Sun. ____**52**____wks/yr

Estimated annual hours of operation _**Boiler is always on stand by position. Hours of operation is not being measured.**_________

From (month) _____________ through (month) ______________

Thermostat set points:

Day: ______**90-70**_______

Night/weekends: ______**90-70**______

Heating Degree Days: ____________________ (see table on page 15)

Comments: **Boiler is very well controlled conventionally. It might be useful if there is a connection between BMS and boiler's protocol. If so, total working hours and detailed failures, alarms and temperatures from boiler should be observed**

6. HVAC Distribution System

Area Served (sq.m.)	Location of Unit(s)
20.000	**Roof**

	PRIMARY	SECONDARY1	SECONDARY2
A. System Type Code	__**1-7-10**___	____________	____________
B. Maintenance Code	____**1**_____	____________	____________
C. Control Code	**1-2-3-4-5-6**_	____________	____________

(A) System Type Code

1. Single Zone
2. Multi Zone
3. Dual duct
4. Variable air volume
5. Single duct reheat
6. 2-pipe water
7. 4-pipe water
8. Window unit
9. Unit ventilator
10. Fan Coil
11. Unit heater
12. Other (define)

(B) Maintenance Code

1. Good
2. Average
3. Fair
4. Poor

(C) Control Code

1. Space thermostat
2. Outside temperature sensors
3. Time clocks
4. Energy management system
5. Auto supply temp reset
6. Economy cycle
7. Heat recovery
8. Other (define)

---

7. Cooling Plant (continued on next page)

Is building mechanically cooled? [**X**]Yes [ ]No

(A) System Type Code __**5**__ (B) Energy Source Code ___**1**____ (C) Maintenance Code ____**1**____

D. Control Code ___**3**____ (E) Voltage Code ____**4**_______

(A) System type code

1. Reciprocating chiller
2. Centrifugal chiller
3. Absorption chiller
4. Solar assisted-absorption chiller
5. Evaporative chiller
6. Heat pulmp
7. DX system
8. Screw compressor
9. Window or thru-wall unit
10. Other (define)

(B) Energy source code

1. Electric Motor
2. Combustion engine
3. Steam turbine
4. Steam boiler
5. Purchased steam

(C) Maintenance Code

1. Good
2. Average
3. Fair
4. Poor

(D) Control Code

1. Manual
2. Somewhat Automated
3. Highly Automated

(E) Voltage Code

1. 120/single phase
2. 208-220/single phase
3. 208-220/3-phase
4. 380 /3-phase

7. Cooling Plant (continued)

Operation Profile:

09^{00} - 22^{30} hrs/weekday….**09^{00} – 23^{00}** hrs/Sat…..**09^{00} – 23^{00}** hrs/Sun…..**28** wks/yr

Estimated Annual hours of Operation : **2674 hrs**

From (month) ______**April**_________through (month) ______**November**__________

---

8. Domestic Hot Water

Domestic Hot Water Heated by:
[ ]Electricity [**X**]**LPG** [ ]Oil [ ]Steam [ ]Heat pump [ ]Other, specify

Number of Units **2**	General Location(s)of Unit(s) **BOILER ROOM**	Is there a re-circulation loop? **YES**
Daily Usage (if known) __**Unknown**___gal/day	Hot Water Temp. At point of Use _____**40**________ At heater _____**45**________	
Temp. of city water **16 °C**	Is tank wrapped? [**X**]Y [ ]N	Do obstructions prevent wrapping? [**X**]Y [ ]N

---

9. Food Preparation and Storage Area Equipment

MARKET / KAFE-REST/ DENİZ KAFE

Item	Exists	Total load(if known) KW	Item	Exists	Total load (if known) KW
Ranges	Yes No	___________	Ovens	**Yes** No	_**10.8 /**____
Steam Tables	Yes No	___________	Frying Tables	**Yes** No	_____**/2.5+1.5**
Freezers	**Yes** No	__**13.5+1.3**__	Refrigerators	**Yes** No	_**4.78 / 1.95**__
Walk-in Refer	Yes No	___________	Walk-in Freezer	**Yes** No	_____**/ 3**____
Infra-red warmer	Yes No	___________	Dishwashers	**Yes** No	_____**/19/ 6**
Microwaves	**Yes** No	___**1.2**_____	Hoods w/Exhaust fans	Yes No	___________
Mixers	Yes No	___________	Other, Define _______________	Yes No	___________

10. Lighting

Building Area*	Type Code of fixture	Approximate number of fixtures	Average watts per fixture	Operating hours/day	Average footcandles**
MARKET	**B**	**654**	**116.2**	**10**	
		196	**34**	**11**	
MAĞAZA	**B**	**950**	**55.6**	**11**	
	A	**1170**	**76.1**	**11**	
KAFE REST.	**B**	**31**	**136**	**6**	
	A	**233**	**43.2**	**6**	
İDARİ BİNA	**A**	**251**	**75.8**	**5**	
	B	**236**	**123.6**	**5**	

Lighting Type Codes

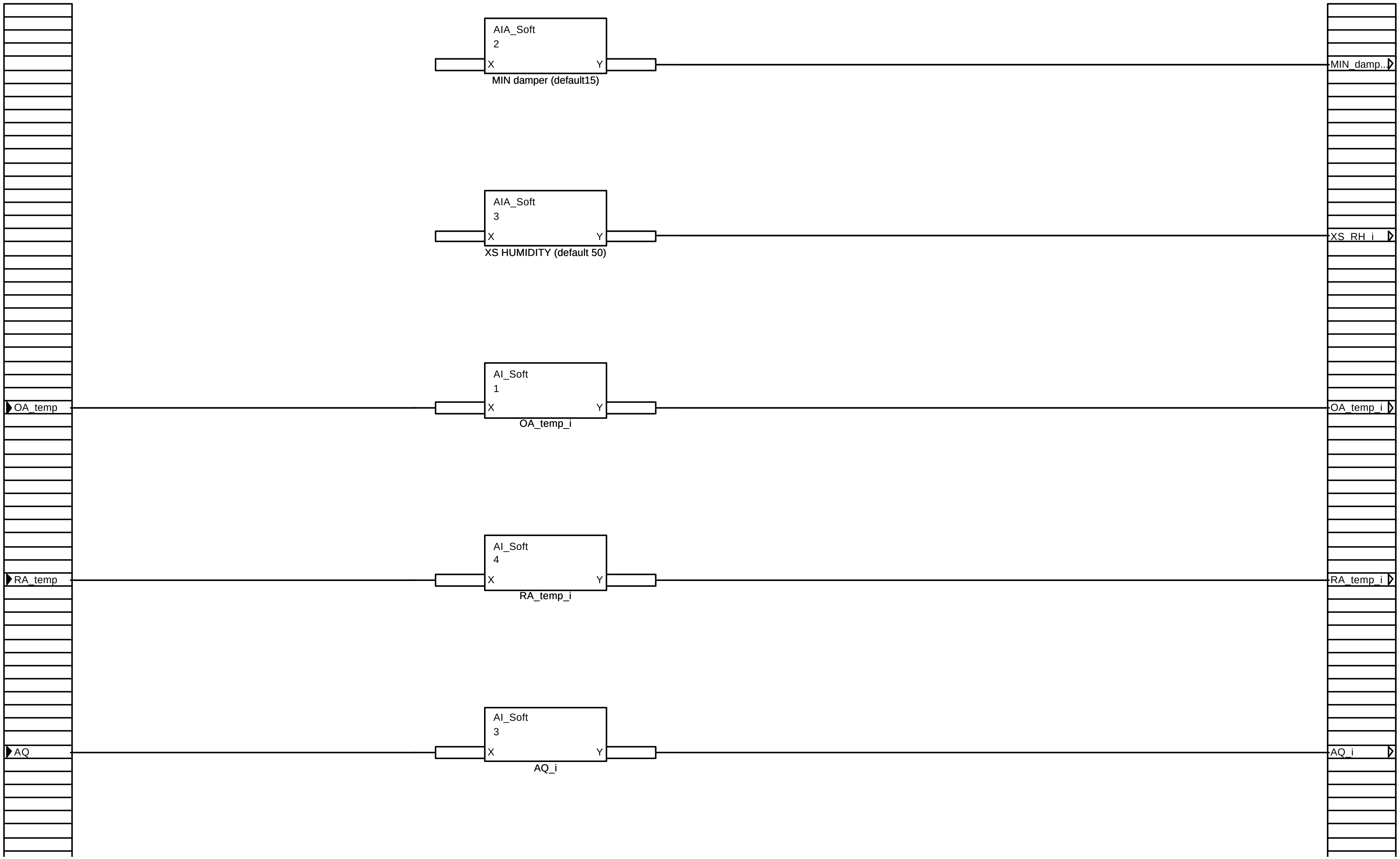
A. Incandescent / Halogen Spotlight
B. Flourescent
C. Mercury Vapor
D. High Pressure Sodium
E. Low Pressure Sodium
F. Metal Halide

*Include indoor and outdoor areas.
** Optional

Comments : (e.g., specially installed energy saving fixtures, bulbs, controls such as wall switchers, time clocks, dimmers, etc.)

APPENDIX B

FUNCTION BLOCK DIAGRAM OF HYPERMARKET AHU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2
X
Y
MIN damper (default15)
MIN_damp...
AIA_Soft
3
X
Y
XS HUMIDITY (default 50)
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OA_temp
AI_Soft
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Y
OA_temp_i
OA_temp_i
RA_temp
AI_Soft
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Y
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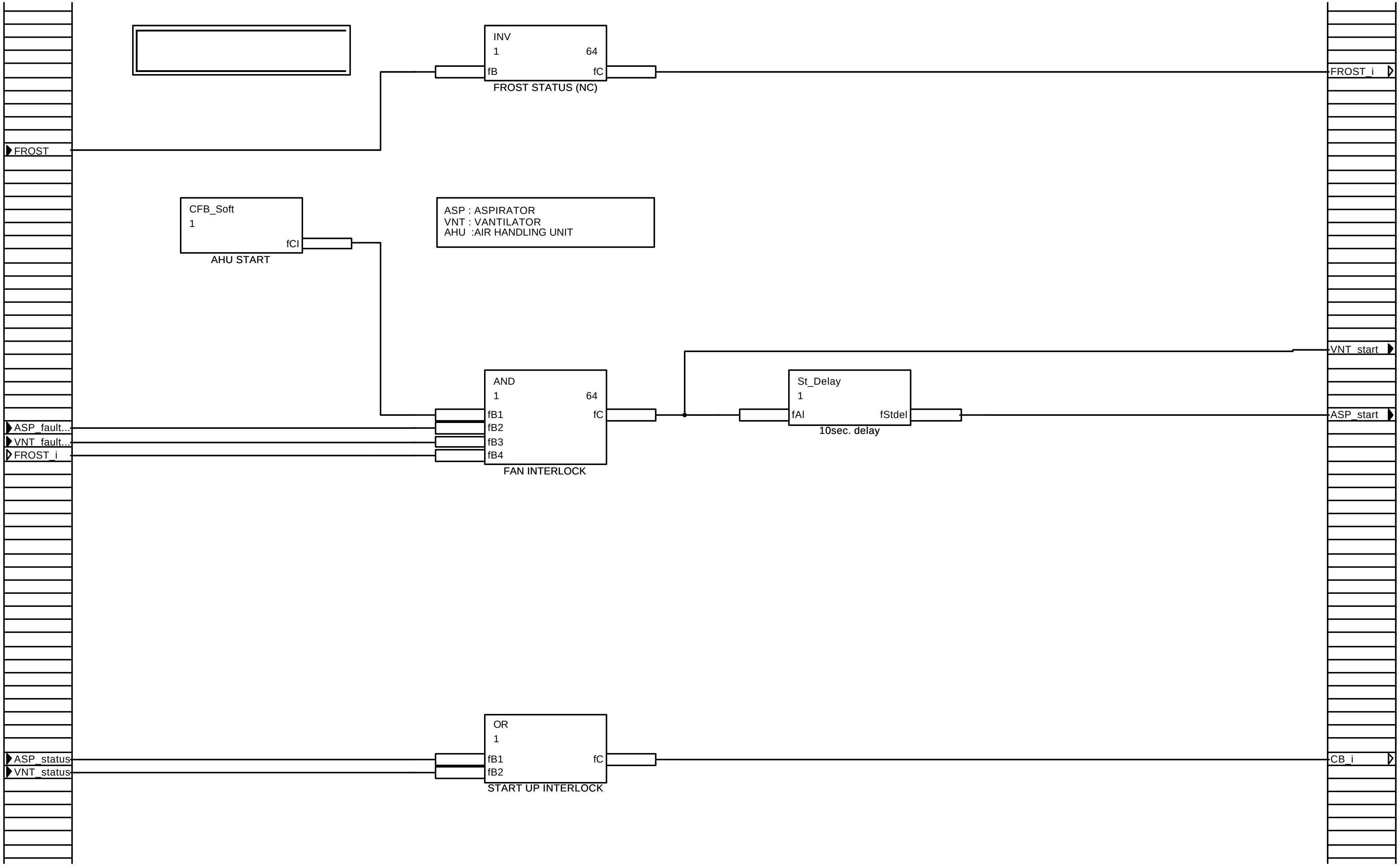
RA_temp_i
AQ
AI_Soft
3
X
Y
AQ_i
AQ_i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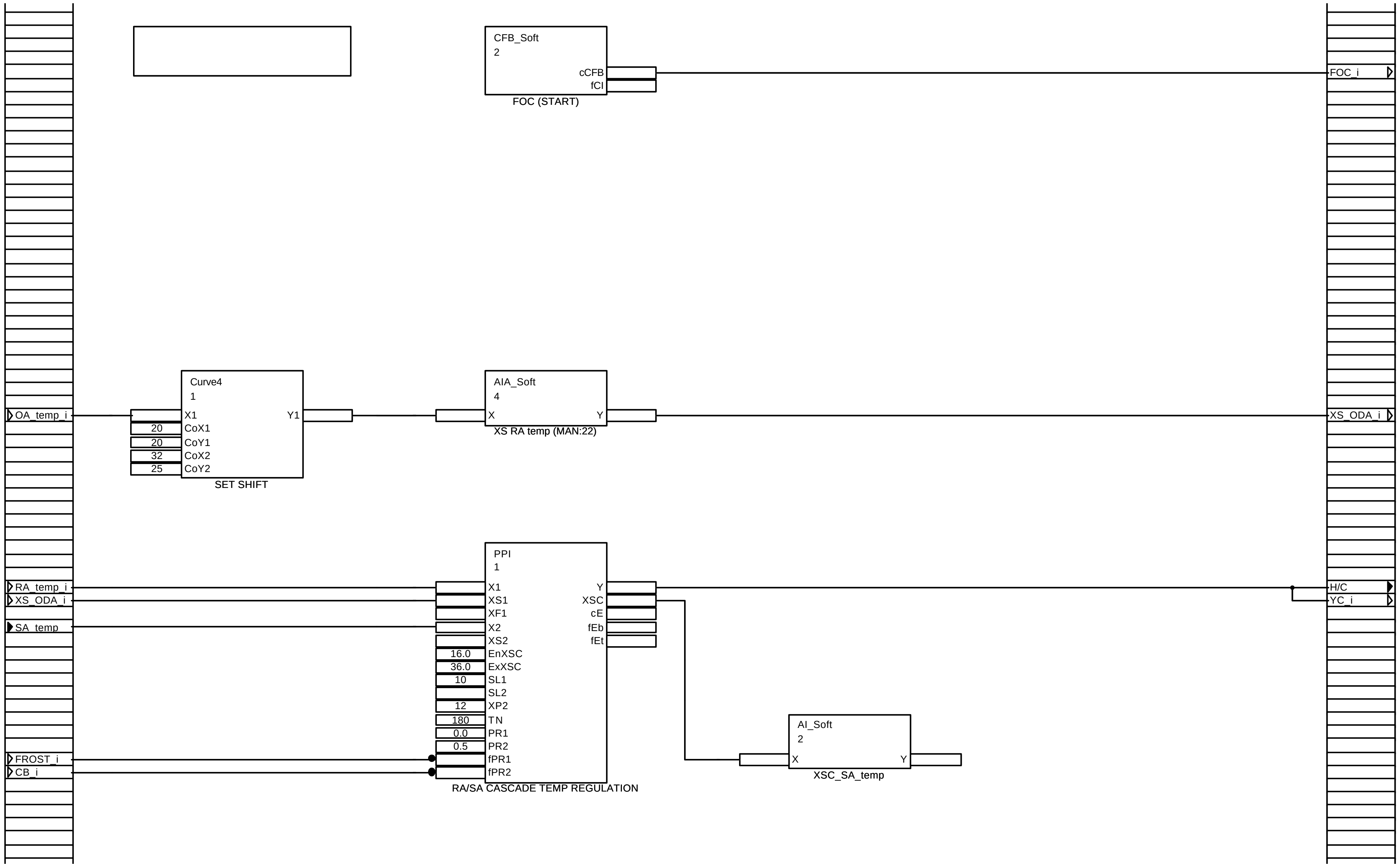
64
fB
fC
FROST STATUS (NC)
FROST_i
FROST
CFB_Soft
1
fCI
AHU START
ASP : ASPIRATOR
VNT : VANTILATOR
AHU :AIR HANDLING UNIT
VNT_start
AND
1
64
fB1
fB2
fB3
fB4
fC
FAN INTERLOCK
St_Delay
1
fAI
fStdel
10sec. delay
ASP_start
ASP_fault...
VNT_fault...
FROST_i
OR
1
fB1
fB2
fC
START UP INTERLOCK
ASP_status
VNT_status
CB_i


CFB_Soft
2
cCFB
fCI
FOC (START)
FOC_i
Curve4
1
OA_temp_i
X1
Y1
20
CoX1
20
CoY1
32
CoX2
25
CoY2
SET SHIFT
AIA_Soft
4
X
Y
XS RA temp (MAN:22)
XS_ODA_i
PPI
1
RA_temp_i
XS_ODA_i
SA_temp
X1
XS1
XF1
X2
XS2
16.0
EnXSC
36.0
ExXSC
10
SL1
SL2
12
XP2
180
TN
0.0
PR1
0.5
PR2
FROST_i
fPR1
CB_i
fPR2
Y
XSC
cE
fEb
fEt
RA/SA CASCADE TEMP REGULATION
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AI_Soft
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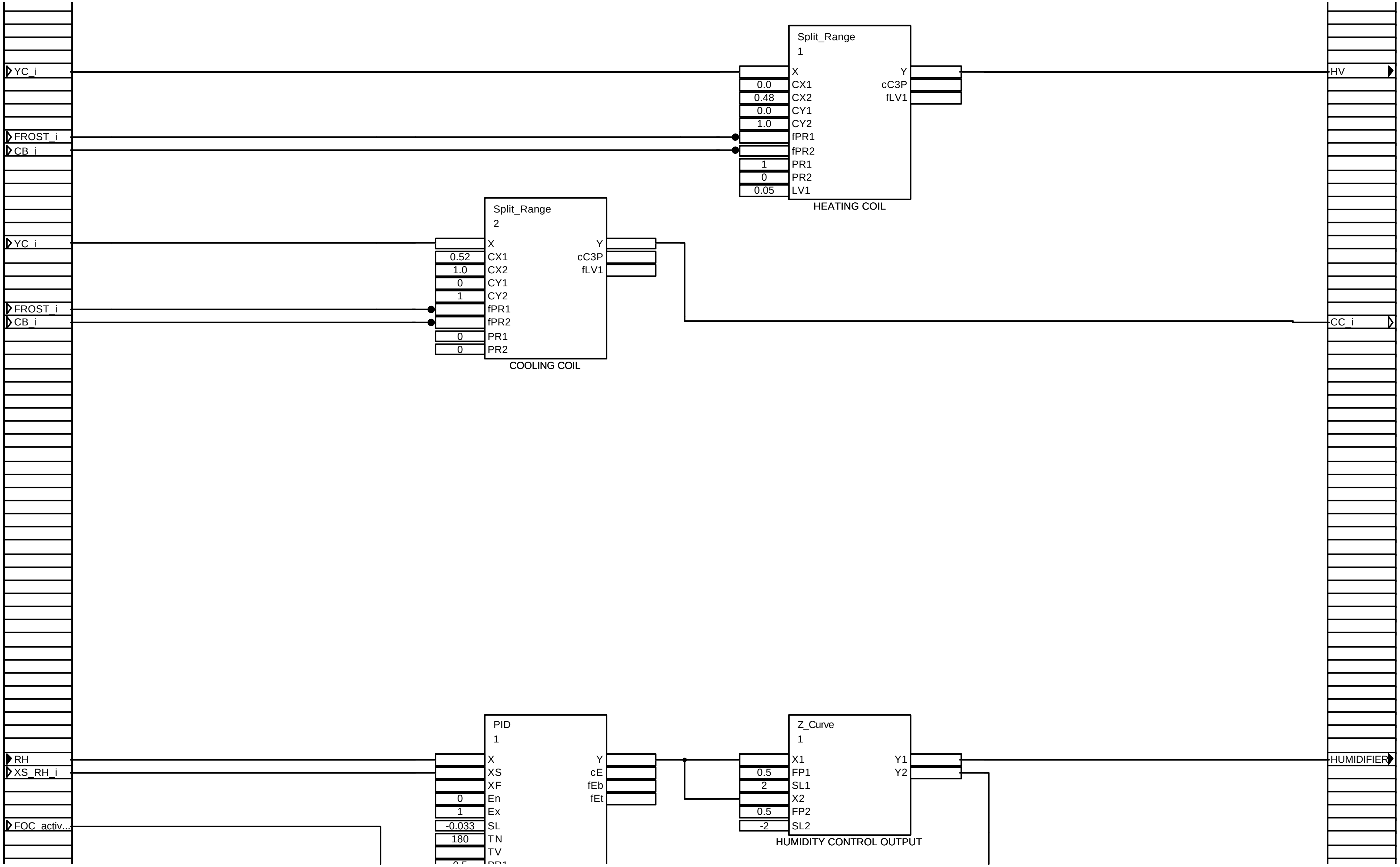
X
Y
XSC_SA_temp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CB_i
YC_i
FROST_i
CB_i
RH
XS_RH_i
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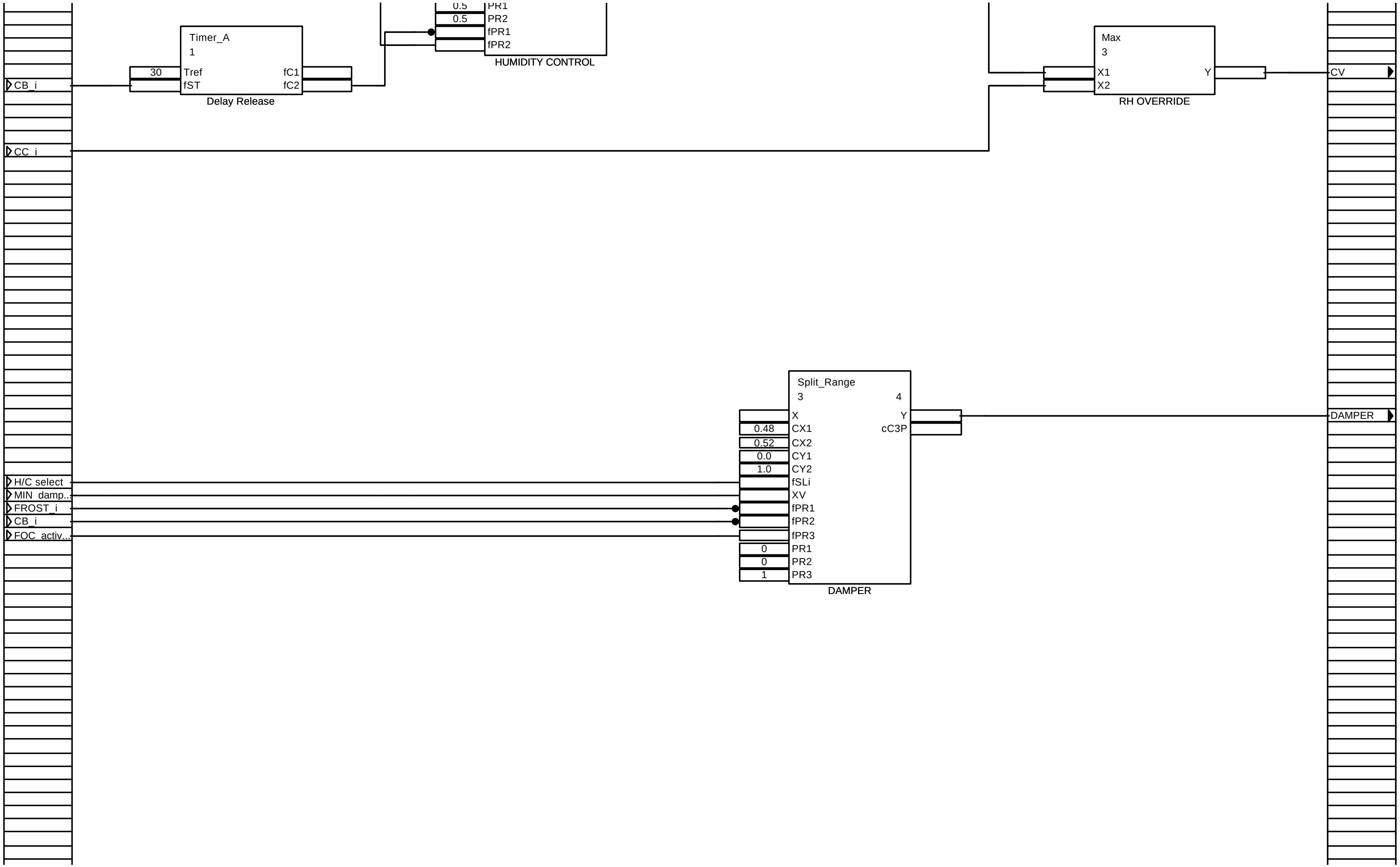
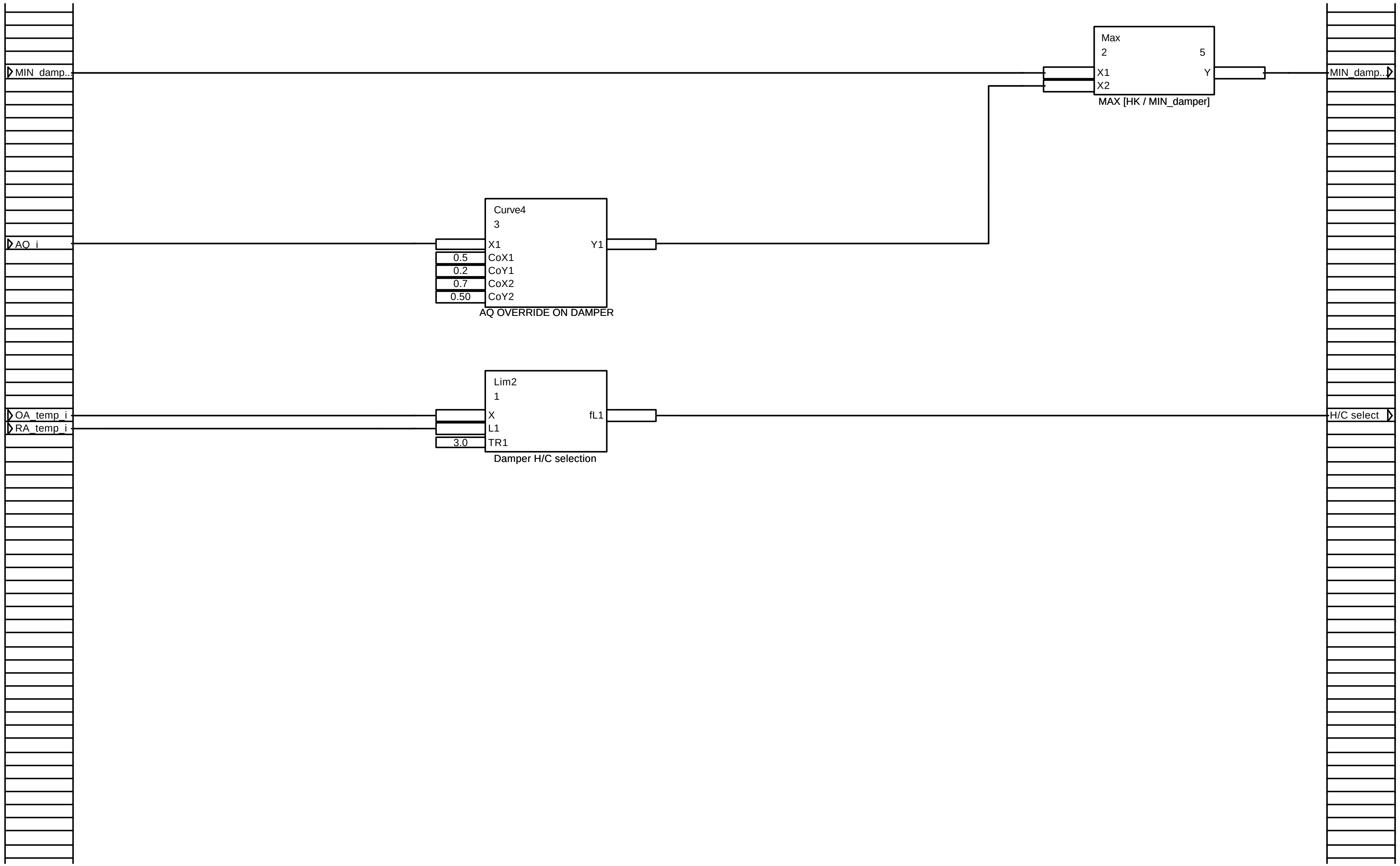
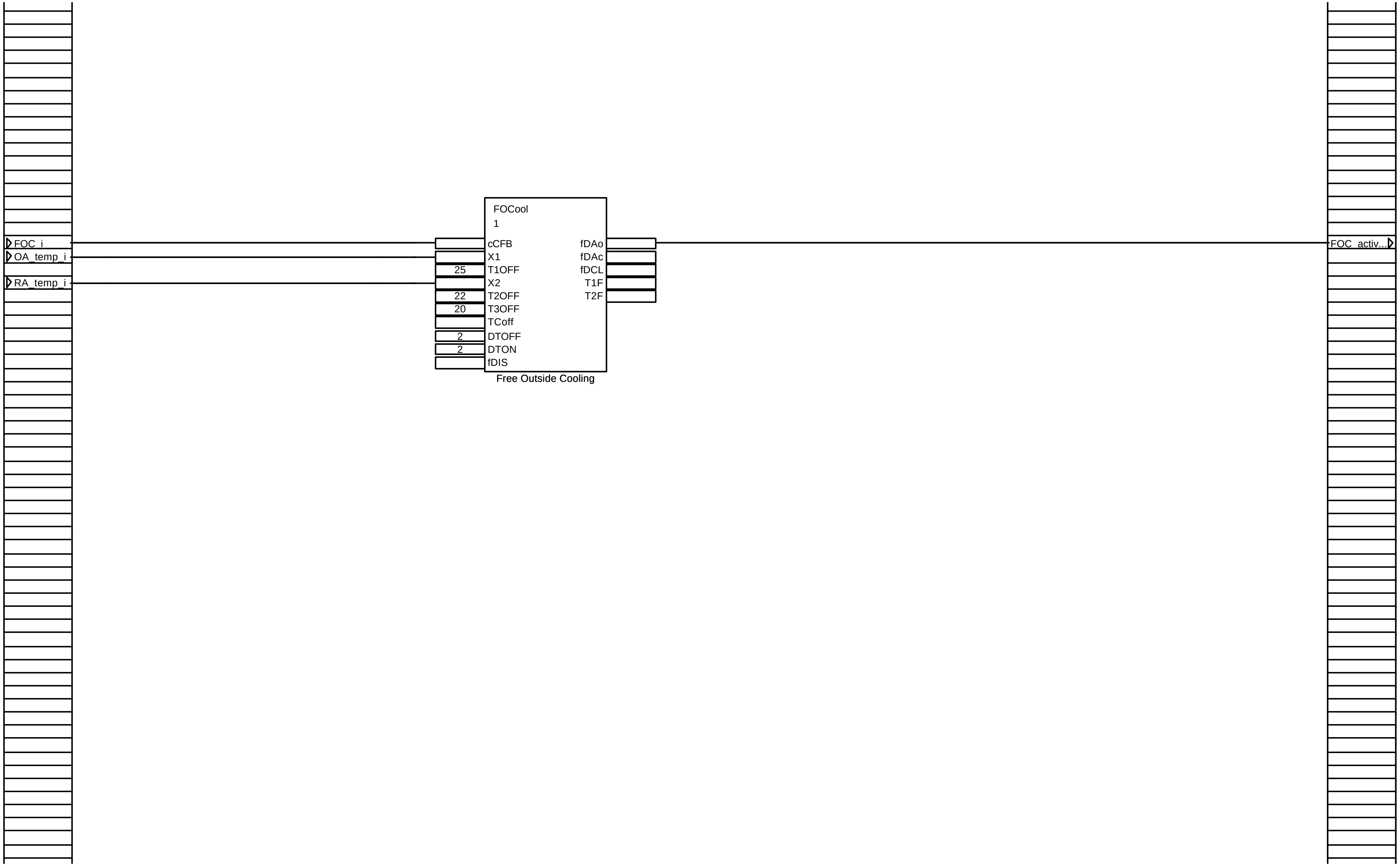
CX1
0.48
CX2
0.0
CY1
1.0
CY2
fPR1
fPR2
1
PR1
0
PR2
0.05
LV1
Y
cC3P
fLV1
HEATING COIL
HV
Split_Range
2
X
0.52
CX1
1.0
CX2
0
CY1
1
CY2
fPR1
fPR2
0
PR1
0
PR2
Y
cC3P
fLV1
COOLING COIL
CC_i
PID
1
X
XS
XF
0
En
1
Ex
-0.033
SL
180
TN
TV
Y
cE
fEb
fEt
Z_Curve
1
X1
0.5
FP1
2
SL1
X2
0.5
FP2
-2
SL2
Y1
Y2
HUMIDITY CONTROL OUTPUT
HUMIDIFIER


0.5 PR1
0.5 PR2
fPR1
fPR2
HUMIDITY CONTROL
Timer_A
1
30 Tref
fST
fC1
fC2
Delay Release
CB_i
CC_i
Max
3
X1
X2
Y
RH OVERRIDE
CV
Split_Range
3
4
X
0.48 CX1
0.52 CX2
0.0 CY1
1.0 CY2
fSLi
XV
fPR1
fPR2
fPR3
0 PR1
0 PR2
1 PR3
Y
cC3P
DAMPER
DAMPER
H/C select
MIN_damp...
FROST_i
CB_i
FOC_activ...


MIN_damp...
AQ_i
OA_temp_i
RA_temp_i
Max
2
5
X1
X2
Y
MAX [HK / MIN_damper]
MIN_damp...
Curve4
3
X1
Y1
0.5
CoX1
0.2
CoY1
0.7
CoX2
0.50
CoY2
AQ OVERRIDE ON DAMPER
Lim2
1
X
fL1
L1
3.0
TR1
Damper H/C selection
H/C select


FOC_i
OA_temp_i
RA_temp_i
FOCool
1
cCFB
X1
25
T1OFF
X2
22
T2OFF
20
T3OFF
TCoff
2
DTOFF
2
DTON
fDIS
fDAo
fDAc
fDCL
T1F
T2F
Free Outside Cooling
FOC_activ...