Energy Conservation

by Time Domain Adaptive Start & Stop Control of HVAC

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Abstract

Usage of HVAC for cooling commercial buildings is ever increasing all over India. Substantial energy is utilized for its operation on a fixed daily time table where time domain adaptive control could be easily adopted for starting and stopping the plant.

This academic article is mainly written for Indian conditions where cooling is the dominant need and for teams responsible for the day to day operation of the HVAC plant.

Introduction

Today, most commercial buildings deploy different kinds of HVAC systems for their comfort needs and fall in *hot & dry; warm & humid; temperate; composite zones*. Population of office buildings in the *cold zone* is very low. HVAC is deployed primarily for cooling function in all the above four zones except cold zone. HVAC consumes almost 50-60 % of the total energy consumption in these commercial buildings and a lot of effort is being taken by the operating staff to control and restrict the energy consumption. The government of India's role through BEE is increasing awareness among the users to conserve energy. The recently published Energy Conservation Building Code (ECBC) places great emphasis on energy conservation. Looking at the ECBC star rating system, one can realize that our buildings have a tremendous potential to conserve energy. The Energy Performance Index (EPI) for our air conditioned buildings far exceeds the targeted EPI of approximately 100 kWh/ m^2/year. A generally averaged EPI for existing Indian buildings is about 250 – 300 kWh/ m^2/ year in a warm & humid climate zone. For example, a building with a load of 7 watts/sq feet or 75 watts/sq

About the Author

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metre operating for 12 hrs a day for 300 days a year shall have an EPI of 270 kWh/m^2/year. The majority of our buildings are located in this warm & humid climate zone. Looking at the gap in EPI for existing buildings one can realize the great potential for energy conservation. Time domain adaptive control may show an energy saving potential of 5 to 7 % approximately in the building HVAC energy consumption. Adaptive control technique has not been practiced so far in India.

Most of our offices / commercial buildings function during the day shift and office operating hours do vary from organization to organization, depending on functional and local requirements. Operating energy consumption constitutes a major proportion in the life cycle costing of our buildings and hence can't be ignored / neglected at all. Constant efforts should be put in by the operating team to discover new energy conservation opportunities. A closer look at our operations can open up several conservation opportunities.

Purpose

What is our requirement for operating office/commercial establishments? The operating team has to start the HVAC system well in advance so that the comfort conditions are achieved by the time normal functioning of business commences. It has been observed that most of the operating staff start their HVAC system one to three hours prior to the office normal business start time. Similarly, comfort conditions are required to be maintained inside till the end of normal business hours. Traditionally, the HVAC system is stopped after closure of the office with some delay. This delay may be due to a very small percentage of people who work late hours. Thus it is not uncommon to see that for an 8 hour normal functioning office, the HVAC plant is operated for 10 to 11 hours traditionally.

Why?

As per the operating best practices for HVAC or first principles of energy conservation, the operating hours for a building, must be minimized to the extent possible so that comfort conditions are just met during the occupied business hours. Operating judiciously can conserve some energy at no or little investment and this aspect must be checked by the operating team. Technically less-qualified operating personnel also can become energy conscious and contribute towards energy conservation. What is required is a little effort from their leadership at the helm to motivate and support the operations team to conserve energy. Stricter discipline and administration of operating hours can conserve a lot of energy for the nation.

How?

The buzzword is adaptive control.

Adaptive control is a vast subject and can involve many variable factors; however we are discussing here a simplified method using time interval for predicting future start / stop.

What is time domain adaptive optimum start stop / control?

An adaptive start /stop control is for controlling an air conditioner or air handling unit so as to reduce energy consumption level during periods of non-occupancy and for energizing an air conditioner / air handling unit before occupancy starts so that the building is comfortable.

Most recent buildings constructed in the corporate sector during the past 10 years have some kind of building automation system (BAS) through which the air conditioning units are started/stopped. However, at present, these are not adaptively controlled. Current practice is to control the start stop functions as per fixed time tables. Some energy can be wasted unknowingly, cooling the building, when there is no occupancy. It is possible to add on the adaptive start-stop control feature to existing BAS/ BMS at minimal costs. It is also possible to use low cost PLCs for controlling stand alone AHU or a group of AHUs for automating adaptive start – stop control as mentioned in the logic of flow diagram, *Figure 1*.

Flow Diagram for Time Domain Adaptive Control System

Nomenclature for the flow diagram

Time: Real time

Schedule: Operational timings fixed by the administration for the business needs.

Delta T: Difference between actual zone temperature and upper comfort limit temperature (during start up) or the difference in actual zone comfort temperature and permissible temperature rise just at closure (during stoppage for non occupancy period)

Adjustment time AT1: Time required in minutes for temperature pull down at start up

Adjustment time AT2: Time required in minutes for temperature increase to upper comfort level or permissible temperature rise at scheduled stop / closure for the day.

Notes & Assumptions

1) Five minute window for addition or subtraction from adjustment time: This is an arbitrarily selected value for entering the subroutine. One can select any other value in minutes. The adjustment time (AT1 for start up & AT2 for shutdown) gets modified adaptively, suiting the seasonal variation. A five minute error is assumed to be a practically acceptable error which is not noticeable by most occupants of the building.

2) Seasonal transition (summer to winter to summer) is a

slow process and hence adaptive step change of five minutes in adjustment time is expected to take place once in 2-3 weeks.

3) Adjustment time (AT1 or AT2) from summer season to winter season may vary considerably; also this may differ for different directions of orientation of the air conditioned zones/spaces.

4) Adaptive system is self correcting at the rate of five minutes (or any other arbitrary value selected by user) per day and the adjustment time gets reduced or prolonged to reach an optimum level in a few days.

5) Stop subroutine is similar to start subroutine shown in the flow chart.

6) A very small amount of heat could be retained and carried over by the thermal mass of a building for a post-holiday day. (For example cooling load on Mondays could be marginally higher than that on Saturdays). A suitable provision in the program (by feeding holiday's calendar to BAS/ BMS) can be made to take care of this additional thermal storage load. It is also possible to add a fixed start time constant (5 or 10 minutes-increment based on experience/ judgment of operation team) for working days preceded by a holiday. Usually, such carry over loads are only 5 to 10 percent in addition to the normal day loads.

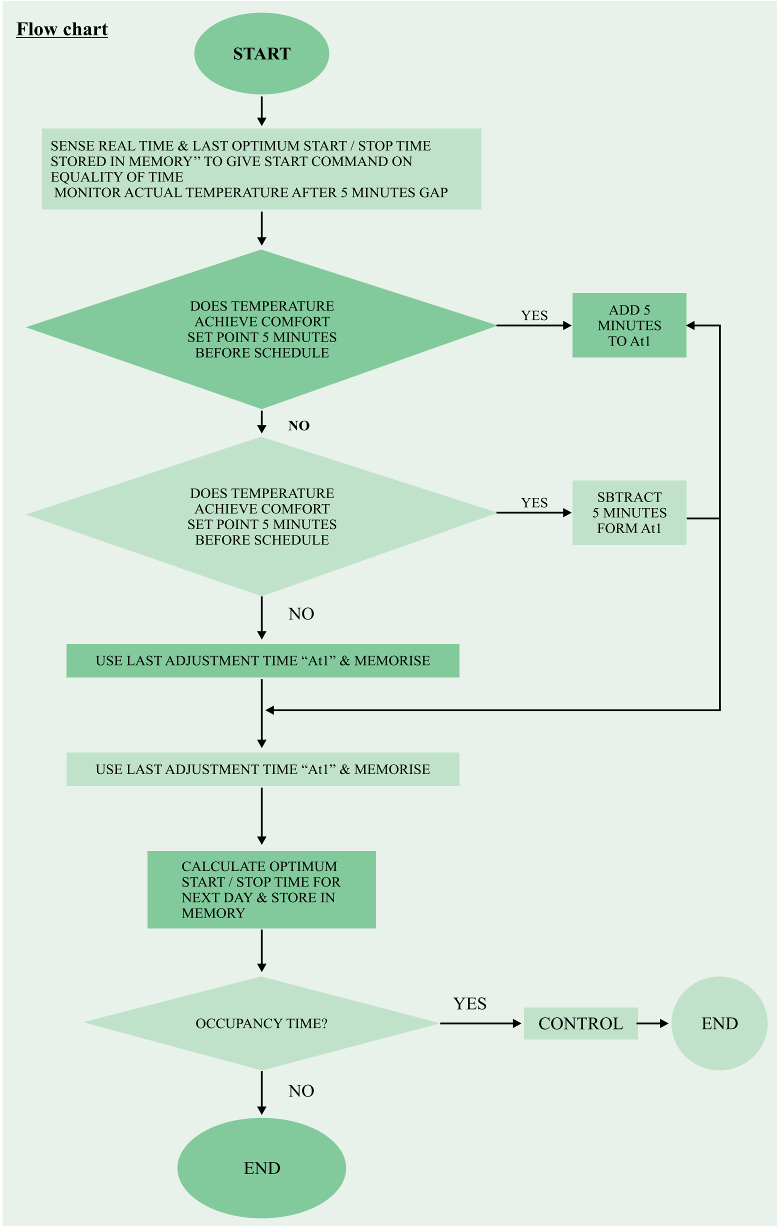

Figure 1: Flow diagram for time domain adaptive control system.

Explanation

The air conditioner or air handling units provided are normally sized for peak loads during the worst ambient conditions and highest internal loads. The ambient environment and internal loads are not at their worst and highest together. Thus the capacity provided is always higher than the capacity required. This extra capacity available within the air conditioning unit determines the temperature pull down rate in a given space. The extra capacity available itself may change from time of usage and other ambient factors like season etc. For example, the temperature pull down may be quite fast in early morning hours than in the afternoon hours. On an average, it should take 15 minutes to 45 minutes to achieve comfort conditions in the office / building after morning start up. However, the pull down time could be lower than this or more than this depending upon the HVAC system capacity provided.

Most offices or commercial establishments have a fixed time schedule for their operations and hence the adaptive control system can correct itself irrespective of the season of the year (whether winter or summer). The seasonal change is gradual over the year and every day, small changes (if required) are being made in the subroutine performed by the adaptive control. Please refer to the flow chart in *Figure 1*. Adaptive control

continued on page 90

continued from page 88

subroutine is periodically entered with a period selected by the user. The period may be one minute, five minutes or any other arbitrary value.

To understand the concept clearly, let us take some values for explanation purpose. Let us say that we want to maintain the space at 23±1°C. Assume the normal office start time is 10:00 hrs. This means if our inside temperature has reached 24°C (upper comfort level) when we enter the office at 10:00 hrs. we are happy. Let us assume that the inside temperature has gone up to 27°C during the night/ non occupied hours The temperature pull down rate for our air conditioning equipment is, say 6°C per hour, then the approximate start adjustment time (AT1) would be calculated as (27-24)/ 6 = 0.5 hrs and thus we could give command to start the air conditioner / AHU at 09:30 hrs.

Similarly, on a warmer day if the inside temperature has risen to say 28°C then the approximate start adjustment time (AT1) would be (28-24)/6 = 0.67 hrs or 40 minutes lead time and the command to start the air conditioner should be at 09:20 hrs.

If suppose we have taken a period of five minutes for performing the subroutine of adaptive control calculation, then the system would give a command to start the air conditioner in such a way that we reach comfort conditions at scheduled start plus or minus five minutes of scheduled building operation time. This is a practically acceptable error and no complaints are expected to be raised as the actual condition is expected to be very close to the comfort set point.

If suppose we have multiple zones with a dedicated HVAC system for each zone, within the same building, then depending on the orientation and other factors like thermal storage and its utilization, air conditioners catering to different zones may start at different times but optimally as discussed above.

Assume that during the occupied period, a space has been maintained at 23°C, the set point given to air conditioner and we are approaching our evening stop schedule. We may allow the temperature to go up slightly, say by one or two °C, within the comfort zone band just at the beginning of the non-occupied period when our air conditioner will be stopped. Let us say, we can allow the temperature to go up to 25°C just at the beginning of the non-occupancy period. Only the refrigeration/chilling circuit (which consumes most of the HVAC power) must be switched off earlier, keeping the air circulation on within the zone, because people are still working in their offices. This air circulation will carry away the heat generated by the occupants / loads to some extent and there will be a gradual temperature rise observed in the absence of refrigeration/ chilling circuit. Comfort related complaints are not likely to be raised as this small temperature change will not be noticed by the occupants.

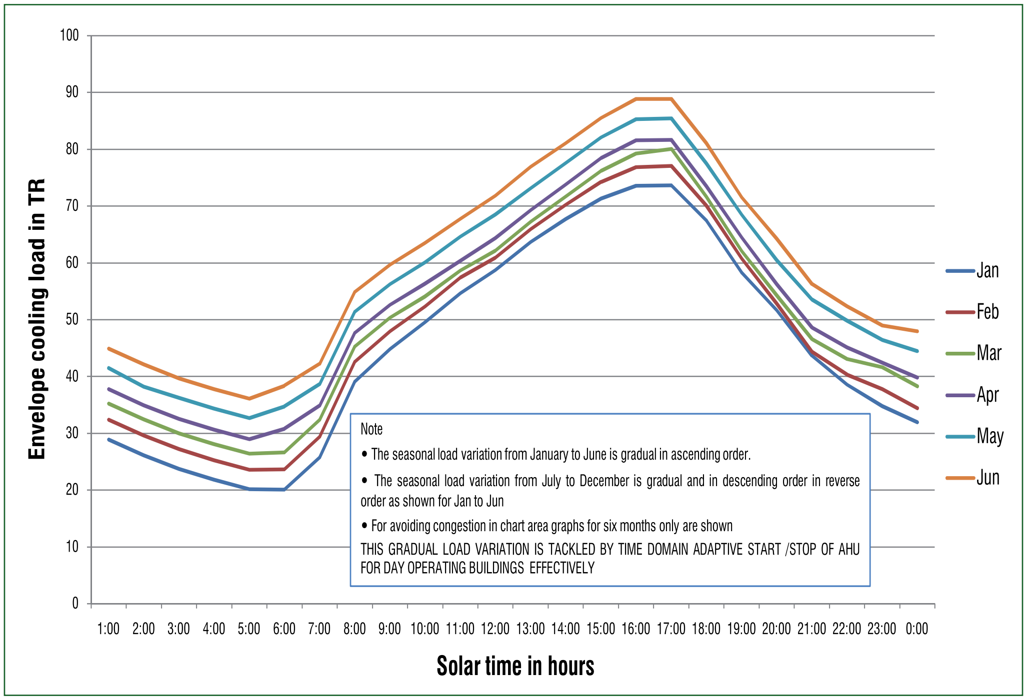

Figure 2: Typical seasonal cooling load (in tons) variation January through June for one particular zone

Let us say this temperature rise is approximately 4°C per hour in the absence of refrigeration/chilling. The adaptive control system will calculate the lead time before stopping as (25-23)/4 = 0.5 hrs. If we wish to allow only 1°C temperature rise then the lead time before air circulation stops at the beginning of non occupancy period would work out to (24-23)/4 = 0.25 hrs.

The adaptive control system would keep in its memory the next day's start and stop time to be utilized for start and stop of the air conditioners and fine tune

continued on page 92

continued from page 90

the same as per today's performance, seasonal requirement and other factors etc.

It is assumed that the internal loads are fairly constant; at the same level on a regular daily pattern. Manual over ride may be required for occasional special events when drastic changes in internal loads are anticipated.

Technical Jargon

A) Cooling load components:

Refer to *Figure 2* showing typical external cooling load variation. It may be noted that the daily variation in external load is very gradual and hence time domain adaptive control fits our requirement.

The figure is for illustration only, to show the reader the gradual increasing changes from January to June and decreasing changes from July to December, in general.

The total building cooling load consists of heat transferred through the building envelope (walls, roof, floor, windows, door etc) and heat generated by occupants, equipments and lights. The load transferred due to heat transfer through the envelope is called external load, while all other loads are called internal loads. The percentage of external versus internal load varies with building type, site, climate and building design. In the typical Indian context, average external load constitutes about 60 to 70 percent of total cooling load. Many new buildings that are coming up use a lot of glass for their external façade for aesthetic reasons. Instantaneous heat gains for large glass usage buildings are high. Their thermal storage capacity is relatively low.

Buildings having a major portion of cooling load due to the envelope can be classified as externally loaded buildings. Majority of Indian buildings fall in this category. Internal heat sources are fairly constant through out the occupancy period. Obviously, from energy efficiency and economics point of view the operations strategy plays a very important role for an externally loaded building.

For manual cooling load calculation method, the most practical to use is the CLTD/SCL/CLF method as described in the *ASHRAE Handbook of Fundamentals 1997 edition*. This method, although not ideal, will yield the most conservative results based on peak load values to be used in sizing equipment. It should be noted that the results obtained from using the CLTD/ CLF method depend largely on the characteristic of the space being considered and how they vary from the model used to generate the CLTD/ CLF data shown in the various tables. Engineering judgment is required in the interpretation of the custom tables and applying appropriate correction factors.

B) CLTD/ SCL/ CLF Method of load calculations:

As mentioned before, the heat gain into the building is not converted to cooling load instantaneously. CLTD (Cooling Load Temperature Difference), SCL (Solar Cooling Load Factor) and CLF (Cooling Load Factor) all include the effect of (1) time lag in conductive heat gain through opaque exterior surfaces and (2) time delay in thermal storage in converting radiant heat gain to cooling load.

This approach allows cooling load to be calculated manually by use of simple multiplication factors.

a) CLTD is a theoretical temperature difference that accounts for the combined effects of inside/outside air temperature difference, daily temperature range, solar radiation and heat storage in the construction assembly/ building mass. It is affected by orientation, tilt, month, day, hour, latitude, etc. CLTD factors are used for adjustment to conductive heat gains from walls, roof floor and glass.

b) CLF accounts for the fact that all the radiant energy that enters the conditioned space at a particular time does not become a part of cooling load instantly. The CLF values for various surfaces have been calculated as functions of solar time and orientation and are available in the form of tables in ASHRAE Handbooks. CLF factors are used for adjustment to heat gains from internal loads such as lights, occupancy, power appliances etc.

c) SCL factors are used for adjustment to transmission heat gains from glass.

C) Heat transfer, Thermal storage, Energy efficiency/ Least cost etc

a) The basic transfer by conduction equation is:

q = U x A x delta T, Where

q = heat gain in Kcal /hr

U = Thermal transmittance for roof / wall/ glass etc in Kcal/ hr. m^2. °C

A = Area of roof/ wall/ glass in m^2.

Delta T = Temperature difference in °C

The heat gain is converted to cooling load using the room transfer function (sol-air temperature) for the rooms with light, medium, heavy thermal characteristics. The equation is modified as

Q = U x A x (CLTD), Where

Q = cooling load Kcal / hr

U = Coefficient of heat transfer for roof/ wall/ glass in Kcal/ hr. m^2. °C

A = Area of roof/ wall/ glass in m^2.

continued on page 94

continued from page 92

CLTD = Cooling Load Temperature Difference °C. The values are determined from tables available in Chapter 28 of ASHRAE Fundamentals Handbook.

Since ASHRAE tables provide hourly CLTD values for one typical set of conditions i.e. maximum temperature of 35°C with mean temperature of 29°C and daily a range of 12°C, the above equation is further adjusted to apply correction factor for conditions given in the mentioned base case.

Thus,

Q (roof) = U x A x CLTD (roof corrected)

b) Thermal storage is the undesired heat gained from sun, environment etc which is slowly released to the conditioned space because of temperature difference between the envelope and the conditioned space. To minimize this inflow of heat for HVAC cooling applications, insulation is applied inside towards the conditioned space. Due to this arrangement, whatever heat is gained by the wall/ roof is thrown back to the atmosphere after sunset and minimum heat is transmitted towards the conditioned space. In cold climate zones the insulation is applied on the exterior of wall/roof etc so that inside conditioned space heat is retained inside and heat does not escape from the conditioned space to the outside environment.

Thermal energy storage is generation of refrigeration during low tariff period in the form of chilled water, ice building etc, (or hot water for cold climates) which is utilized during high tariff periods. Suitable mechanism is provided to store, distribute and control the thermal energy stored. For the sake of argument, walls, roof etc can't be called as thermal energy storages. They don't have any regulating mechanism to give away the cold as per our requirement. Also, if we cool the walls etc., it is likely that the deliberate extra energy used for cooling walls may be lost to the atmosphere and only a fraction of this stored energy (cold) may act as a hedge against peak solar gains. Also, if internal insulation is provided on the walls, then it is very difficult to store cold in the walls as thermal energy storage.

Once again, going back to the cooling load equation, we can see that U and A in this cooling load equation are constant. CLTD, which is a variable and under our control, dictates the cooling load. Lower the CLTD, lesser is the cooling load. Lesser the operating time lesser the energy consumed. It is possible that instantaneous load on HVAC with adaptive control could be slightly higher than the prolonged hours in traditional operation method trying to cool the walls, furnishing, glass etc during non-occupancy hours. It is felt that adaptive control could achieve the minimum for energy consumption.

Inference

Time domain adaptive start / stop control for HVAC holds good energy conservation potential.

Reference

ASHRAE Handbook of Fundamentals 1997.