Eighth International IBPSA Conference
Eindhoven, Netherlands
August 11-14, 2003

ENERGETIC OPTIMAL HEATING AND COOLING CURVES (FOR AIR SUPPLY)

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ABSTRACT

New Dutch office buildings are built under strict energy efficient legislation and well equipped with insulation, condensing boilers, heat recovery systems, etc. Despite this, many buildings don't perform as energy efficiently as expected. Also comfort problems occur in large numbers. The problem seems to be the frequently used conventional control strategies, most of which were developed at a time when buildings had no insulation and were equipped only with single glazing. These common used conventional strategies in the Netherlands are: supply air temperature of 20 °C in winter and 16 °C during summer. When these conventional strategies are used in modern office buildings, much energy is spoiled due to a mismatch between heating and cooling demands and supply on central and local level. In the intermediate season heat is supplied at central level in order to condition the supply air while at local level cooling is supplied to cool the room air temperature to its setpoint. This heating and cooling at the same moment is a non-desirable situation.

In this paper a method is described how to determine the supply air temperature settings in order to minimise the energy spoiled due to mismatches in supply and demand. The method uses building simulation to derive the optimised temperature set points. Application of this method will give energetic optimal heating and cooling curves.

Energy savings of up to 35% can be realised without significant financial investments by devoting extra attention to the settings of the central AHU in HVAC systems without loss of comfort. In most cases the number of comfort complaints will also be reduced. The design method can be used in both new and existing buildings.

This paper presents:

a) A brief description of the method used to realise this energy saving.

b) A practical example

c) How this method is integrated in a building simulation tool.

INTRODUCTION

The majority of Dutch office buildings are equipped with HVAC systems that condition the supply air in a centralised Air Handling Unit (AHU). A heating/cooling curve, as part of the control strategy, is used to condition the supply air. The common used settings to adjust the heating/cooling curve in most office buildings lead to problems relating to occupant comfort and excessive energy consumption. Even in new office buildings, well build under the strict legislation, or in retrofit buildings the same problems occur and the predicted energy consumption or energy savings are far out of reach.

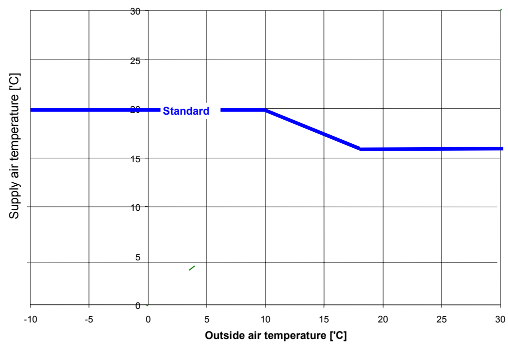

Figure 1: Standard heating/cooling curve for AHU

Excessive energy consumption occurs during the transition between cooling and heating period (40% of the year). In this period there is a demand for heating and cooling at the same time. The common used heating/cooling curve doesn't fit the energy demands with the energy supply. Figure 1 shows the standard heating cooling curve for an AHU. Figure 2 shows the energy (heating and cooling) demand profile for a typical office building. On the horizontal axis the outside air temperature is given, on the vertical axis the hourly energy demand is given. The hourly energy demand is calculated by building simulation. In order to determine the actual energy demand the simulation is done without any conditioning of the supply air. The local set points used are: 22 °C for heating, 24 °C for cooling. In this case the supply air temperature equals the outside temperature plus a temperature raise due to fan dissipation.

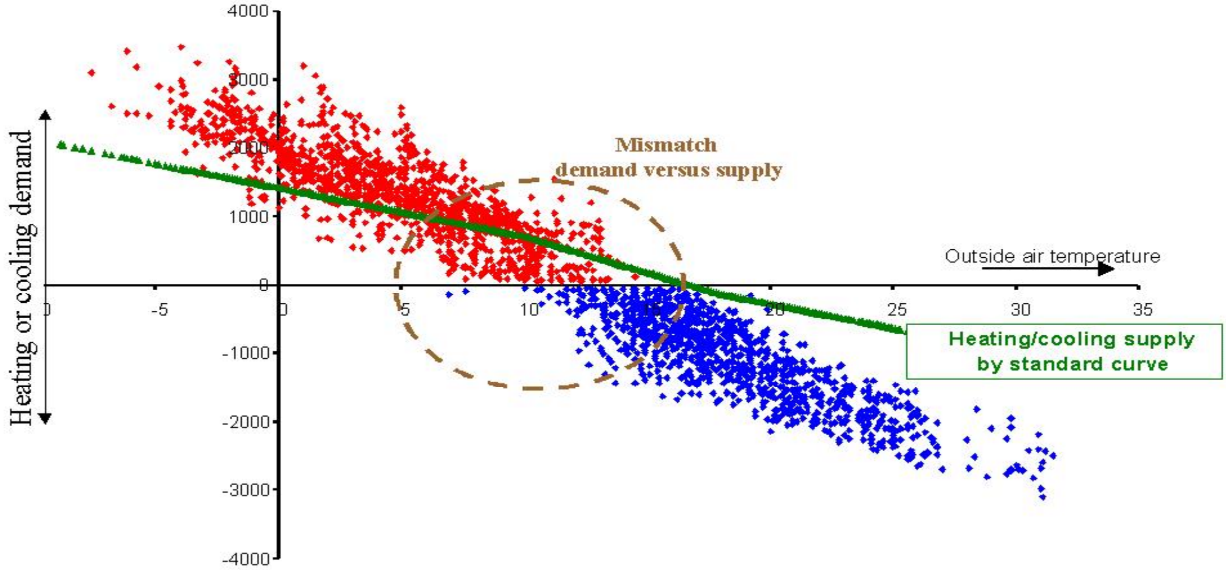

Figure 2: Energy demand profile showing energy mismatch due to standard heating/cooling curve

The dotted line with the label "heating/cooling supply by standard curve"in figure 2 is the energy needed in order to condition the supply air according to the conventional heating/cooling curve from figure 1.

During the transition period (ranging from 5 °C till 15 °C) a large number of hours occur for which there is a mismatch in centrally supplied heat and locally needed heat/cold. For modern office buildings during this transition period too much heat is supplied with the supply air using a conventional control strategy. In a number of hours this leads to temperatures well above set point or even above the cooling set point, which requires cooling energy.

In order to avoid this mismatch between centrally supplied energy and locally needed energy, the centrally supplied energy should be lowered so that in none of the circumstances too much energy is supplied centrally (solid line with no individual room control, air in figure 3). All additional energy is supplied locally by heating at outside temperatures below the transition range or by cooling above this range. The dashed line is the maximum of energy that can be supplied by the combination of the central system and the local terminal units with individual room control. This puts restrictions on the system concepts for which this method is applicable. The system must have a capability to supply heat or cold directly at a room level with individual control.

The energy supply profile can be transformed to air supply temperatures by taking into account the ventilation rate. In figure 4 the solid line for the air supply from figure 3 is transformed to the heating cooling curve line in figure 4.

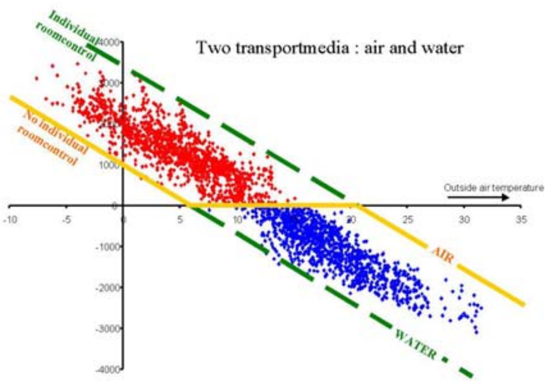

Figure 3: Optimised central energy supply

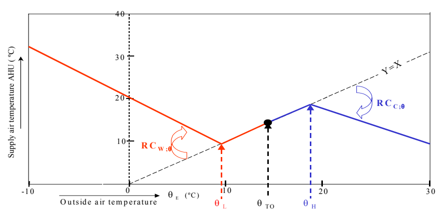

Figure 4: Optimised heating/cooling curve.

This transformation is done by the following formula.

$$T_{supply\ air} = Q_{demand} / [\dot{V} \cdot \rho \cdot C_p] + T_{ouside} \qquad (1)$$

With:

$T_{supply\ air}$ Supply air temperature (°C);
Q_{demand} Energy demand for cooling or heating (W);
$\dot{V}$ Ventilation rate of the supply air (m^3/s);
P Specific mass of the supply air (kg/m^3);
C_p Specfic heat of the supply air (J/kg.K);
T_{ouside} Ouside air temperature (°C)

The energetically optimised heating/cooling curve can be characterised by a transition temperature θ_{TO} (at this outside temperature the building is in thermal equilibrium with its environment), the boundaries of the transition range θ_L and θ_H and a direction coefficient for the cooling and the heating part. The dotted line in figure 4 indicates the curve at which the supplied temperature equals the outside temperature.

DESCRIPTION OF THE METHOD

The design method is based on the hourly heating and cooling demand within the building, which can be determined using a building simulation program such as the Dutch computer program VA114 (VABI 2003),(Plokker 1989). This building simualtion tool is a dynamic building energy simualtion tool, which is used by almost all leading consultancy firms in the Netherlands. It is also possible to use a more simplified design method. This method is published in the Dutch ISSO publication 68 (Elkhuizen *et al,*2002). The method is cut into 5 major steps. Figure 5 shows these 5 major steps.

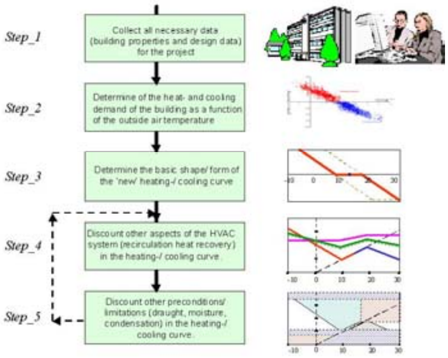

Figure 5: Steps of the method

Who can use the calculation method?

Customers, for whom the design method is developed, are: (1) designers, (2) installers, (3) building managers, (4) TAB (Testing, Adjusting and Balancing) companies. The method will be available as a computer application in VABI building simulation tool VA114.

Step 1: Collect all necessary data

Step 1 is based on the collection of the necessary 'Project' data, which are relevant for the determination of the Energetically Optimised Heating/Cooling Curve. The 'project' parameters/data are related to (1) the building properties, (2) the type of HVAC system, (3) the building user.

Step 2: Determine the heating and cooling demand as a function of the outside temperature.

Step 2 is the determination of the heating/cooling demand of the building as function of the outside air temperature. The determination of the heating/cooling demand of the building is a complex analysis and is based on the use of building simulation programmes. Because not everybody is able to work with sophisticated building simulation programmes, a simplified method has been developed to solve this problem.

Step 3: Determine the basic shape of the new curve

Step 3 is a very important step. In a new design, the designer has to make his principle choice for the type of HVAC system and how the required capacity is split over the air and water supply.

The basic shape of the Energetically Optimised Heating/Cooling Curve is determined and is thus a description of the heating and cooling production of the HVAC system. This will be done on the outcome of the calculated heating and cooling demand as calculated in step 2. The results of step 3 are:

- The calculated value of the transition temperature (free temperature) of the building. The transition temperature is the temperature where no heating or cooling is required.
- The transition range
- The sensitivity of the heating and cooling demand in relation to the outside air temperature.

Step 4: Discount other aspects of the HVAC system in the heating/ cooling curve

Discount the energetic contribution of the different HVAC components (AHU, fans, heat recovery, etc.) into the basic shape (step 3) of the heating/cooling curve. A number of aspects of the air-conditioning system that affect the heating and cooling supply have not yet been included. These aspects are as follows:

- Heat recovery (affects the heating and cooling supply in the air-handling unit).
- Re-circulation (affects the temperature level of the heating/cooling curve).

The use of a heat recovery system in the HVAC system should not be conflicting with the optimum heating/cooling curve. It is important to make sure that when the heat recovery system is operated the optimum energetic heating/cooling curve is not exceeded and/or that the cooling curve is not fallen short of. The heat recovery system may only be operated if water humidifying is applied so that the fall in temperature in the air humidifier can be compensated with the extra-recovered heat.

Step 5: Discount other preconditions limitations in the heating/cooling curve.

The effect of the physical boundary conditions of the HVAC system should be taken into account. It gives the limit within which the heating/cooling curve could be defined without complaints being received from the users of the building.

If the boundary conditions as calculated in this step hinder the right choice of the heating/cooling curve, it may be necessary that the design conditions of the HVAC system must be adjusted. In this case we will have to go back to step 4.

Preconditions such as:

- Comfort aspects
- Condensing risks
- Characteristics of air supply grids
- Humidifying and dehumidifying
- Draught risks

The major effect of these risks is that the freedom of design is limited to avoid problems. Figure 6 shows the boundaries of different risks related to the heating/cooling curve.

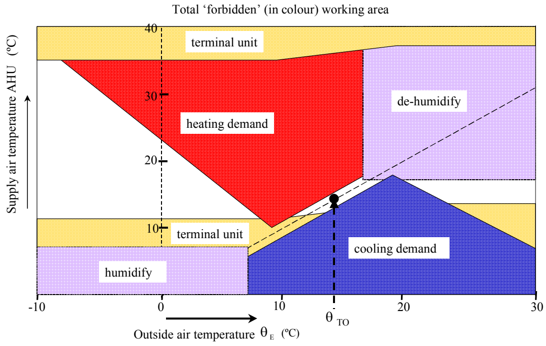

Figure 6 boundaries imposed by the system concept

The five different areas in figure 6 are dependend on the system concept and building and operational characteristics.

- Terminal unit. Dependend on the type of air inletgrill. The type of grill determins the minimum and maximum supply airtemperature.
- Humidity. If the supply air temperature is in this region the room air will be to dry.
- De-humidify. If the supply air is in this region a lot of energy will put into de-humidification.
- Heating demand. This region follows from the heating and cooling optimisation methode. This region is dependend on the building characteristics and the expected loads in the building. Supply air temperatures in this region will lead cooling on the room level.
- Cooling demand. This region also follows from the heating and cooling optimisation methode. Supply air tempeartures in this region will lead to heating at room level.

The remaining white region indicates the region in which the designer is free to choose his control strategy.

A PRACTICAL EXAMPLE

Sample building

This example relates to a recently completed office building (year of construction: 1998).
A representative ground plan and the façade view are shown in figure 7.

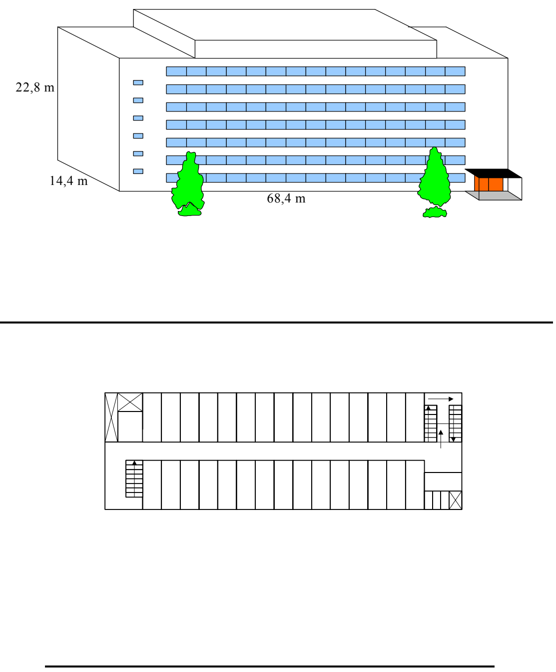

Figure 7: The ground plan and the façade of the selected building

Building

- RC value building shell: 2.5 [$m^2 \cdot K/W$]
- Window percentage exterior (North and South wall): 40 %
- Gross Floor Area (FGA): 6,895 m^2
- Window system (HR+ glass) U value glass = 1.5 [$W/(m^2 \cdot K)$]: ZTA value glass = 0.60

Organisation

- Average internal heat production workspaces: 35 [W/m2 North East] (including frequency of use)

HVAC system

- Heated/cooled ventilation air, heating and cooling by means of 4-pipe induction system
- Set point: winter = 22 °C; summer = 24 °C
- Quantity of fresh air per person: 50 m^3/h per person

The energy saving that can be realised by adjusting the heating and cooling curve from the standard curve to the energetically optimised heating and cooling curve for the ‘case’ building is as follows:

For cooling 10 %

For heating 13 %

If an organisation with an average internal thermal load and equal to the thermal load as specified in the operational requirements (= 50 W/m2 N.E.) is occupying the same sample building, the energy saving is even higher (36 % for heating and 19 % for cooling).

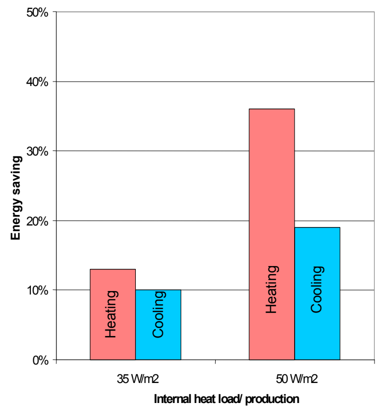

Figure 8: Calculated energy savings

Improved comfort

The comfort improvement is showed in figure 9 by comparing the occurring room temperatures in the ‘case’ building to the temperatures specified for the standard heating and cooling curve (in red colour) and the energetically optimised heating and cooling curve (in blue colour).
The situation with the standard heating/cooling curve shows that the room temperatures of 24 °C (set point cooling) occur at an outside temperature of 4 °C (figure 9). In the case of the energetically optimised heating and cooling curve, these room temperatures do not occur until an outside temperature of 10 °C is reached.
High room temperatures in a winter situation will lead to complaints regarding the thermal comfort.
The number of comfort-related complaints is reduced considerably when the energetically optimised heating and cooling curve is applied.

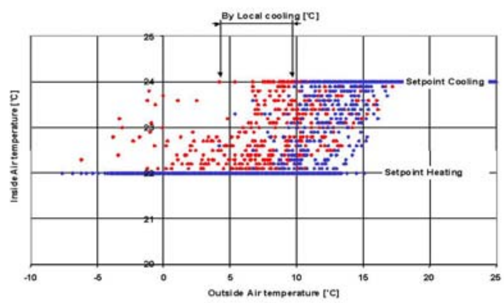

Figure 9: Improved comfort through adjusting the heating /cooling curve

INTEGRATION IN A BUILDING SIMULATION TOOL

The methode described above is integrated in a Dutch building simulation tool (VA114). A user can select to calculate on optimesed heating/cooling at the moment he has entered the input for a simulation run. Five runs are performed in batch mode. The first three are runs to generate a building energy demand profile. In the three runs the internal loads are varied. On this profile a statistical analysis is done with linear regression in order to determine the parametrs that describe the optimised heating curve. The fourth run is done with this optimised heating and cooling curve. The fith and final run is done with the heating and cooling curve given by the user so that the improvements in energy consumption and comfort can be determined.

CONCLUSION

- Use of general common (standard) heating/ cooling curves can contributes to complaints of comfort and to high energy consumption.
- The design methode changes the way we look at the design process of HVAC installations. The designer determines at first the heating and cooling demands and then the matching type of HVAC system. The heating and cooling demand year profile can be used as a strong communication mean to explain the principle choices that are made in the design process.
- Every time a building has a major change in internal heat loads, organisation, insulation, etc. The heating/cooling curve should be redesigned!
- When a building has a major retrofit the full benefit of the taken measures will only come to account when the heating/cooling curve is redesigned. The heating/cooling curves affect the total system (building and HVAC) efficiency.
- The method described in this paper shows the serious need of an optimal tuning of heating/ cooling curves in HVAC systems;
- The optimal heating/ cooling curve is determined by building physics and building loads;
- Retrofit of buildings require re-tuning of the heating/ cooling curves;
- Important change in building use or internal heating load required re-tuning of the heating/ cooling curve;
- The energy saving potential of optimal heating curves presents an expected energy saving of 5 – 35 % in relation with common heating curves.

ACKNOWLEDGMENT

This project was a co-operation between ISSO, TNO Building and Construction Research, VABI and NOVEM, the Dutch Energy and Environmental Agency.

TNO Bouw did the theoretical development of the design method. NOVEM was the main financial sponsor to the project and ISSO chaired the scientific steering group committee.

We would like to acknowledge the members of the ISSO steering group committee for their timely, insightful and constructive criticism during the execution of the work.

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