THE EFFECT OF OPTIMAL TUNING OF THE HEATING-/ COOLING CURVE IN AHU OF HVAC SYSTEM IN REAL PRACTISE

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ABSTRACT

Energy savings can be realised without significant financial investments by devoting extra attention to the settings of the heating/ cooling curve in the central Air Handling Unit's (AHU's) of HVAC systems without loss of comfort. In most cases the number of complaints will also be reduced. The method can be used in both new and existing buildings.

The approach will generate a building-specific heating/cooling curve based on an energetic optimum between the demand for heating and cooling in the zone's. The input data used to generate the function cover the characteristics of the building, the organisation, and the HVAC equipment. A secondary effect for HVAC designers is that the way they design the type of installation can be changed. They will be able to see if their chosen HVAC system for the building design fits with the needs of the client.

The method described in this paper shows the serious need of an optimal tuning of heating/ cooling curves in HVAC systems and how to use heat recovery systems and recirculation of the exhaust air in the right way and how they should be controlled and taken into account.
Use of general common (standard) heating/ cooling curves can lead to many complaints of comfort and to high energy consumption. 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.
In real practise, the effect of retuning of the heating/ cooling curve of the central AHU on energy savings is in the presented buildings for heating between 10 – 25 % and for cooling between 10 – 35 %;
The full benefits of this method will only come to account if the HVAC system is proper hydraulically and air balanced.

KEYWORDS
HVAC systems, control strategies, energy saving, improved comfort, design tool, heating-/ cooling curves, Re-commissioning tool.

INTRODUCTION
New Dutch office buildings are built under strict energy efficient legislation and are well equipped with insulation, condensing boilers, heat recovery systems, etc. Despite this, many buildings don't perform very energy efficiently and the comfort requirements. This has led to a large number of complaints. The problem seems to be that 'common' energy control strategies (heating/ cooling curves) are often used, most of the curves were based on buildings with low level of building shell heating resistance and no additional insulation and single glazing. When these control strategies are used in modern office buildings, too much energy is used due to a mismatch between heating and cooling demands.

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 to the zones. The common used settings to adjust the heating/cooling curve in most office buildings lead to problems relating to user comfort and excessive energy consumption. Even in the new office buildings, well-built under the strict legislation, or in retrofit buildings the same problems occur and the predicted energy consumption or energy savings are unobtainable. Several studies on energy consumption confirm the existing gap between prediction and reality. Figure 1 shows the interaction between the central AHU and the cooling demand in the zones.

The first part of this paper presents a brief description of the method used to realise this energy saving. The brief description follows with a practical example executed in a real office building. The effect of energy saving will be quantified for six buildings.

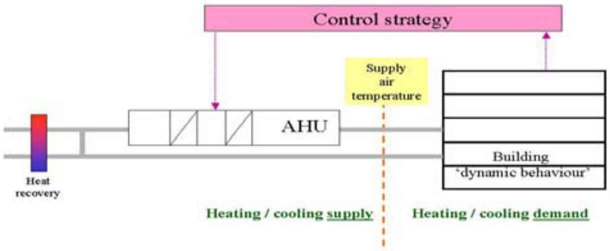

Figure 1. The control strategy determines the supply air temperature as a respond to the dynamic behaviour of the building

The energetically optimized heating/cooling curve will help to decrease the existing gap between prediction and reality. The heating/cooling curves where for a long time were no subject to further research and were a forgotten subject. This project shows that it is a very interesting subject for research, since there is a strong relation between the actual heating/cooling curve and energy consumption and comfort.

In the Dutch mild climate the need for space heating is reduced due insulation and air tightness, but on the other hand, the need for room cooling is increased. During normal winter conditions or during summer conditions there seems no problem, there is a full load condition. But, with moderate temperatures there is a part load condition and a need for cooling and heating at the same time. Figure 2 shows a typical 'modern' building heating and cooling demand profile. The demand for heating and cooling at the same time occur at 40% of the time.

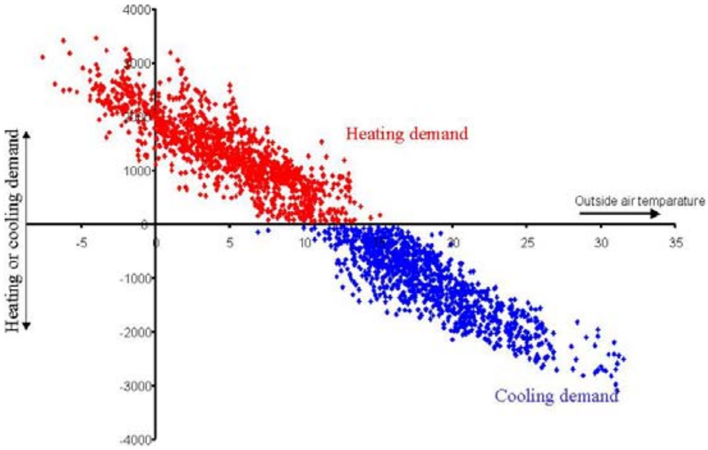

Figure 2. Building related heating and cooling demand profile over a year period (data points per hour).

The control strategy determines how the HVAC installation responds to these conflicting energy demands. In the majority of the buildings there will be a contradictory heating and cooling supply at the same time, which will lead to excessive energy consumption. The development of control strategies has stood still. The most commonly used control strategies were developed during a time when buildings had no insulation or double glazing and high internal heat loads, so the energy profile was clear. The standard control strategy fulfilled with no real problem, either you needed cooling or you needed heating. The question why the building should be controlled in that manner was never asked.

The problem that nowadays occur with modern build office buildings or retrofit office building is that the control strategy doesn't fit the energy demands with the energy supply, too much energy is used due to a mismatch between demands and supply. Not only too much energy is used but there are also more comfort-related complaints than expected. In order to optimise the energy consumption and to reduce the complaints there should be much more attention to the control strategy and the heating/cooling curve.

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Despite many years of optimisation of single components, such as condensing boilers, there is no common knowledge about how to design your control strategy or how to design the heating/cooling curve. The fact is that there is no literature known about the relation between comfort, energy efficiency or energy consumption and heating/cooling curves.

TNO Building and Construction Research developed the design method called "Energetically optimised cooling/ heating curves", which allows designers and facility managers to design and check the optimal settings for their office buildings. The design method generates a building-specific heating/cooling curve for the centralised AHU system, which is optimally tuned to the building and the organisation occupying it. The optimal settings relate to the building's heating and cooling requirements and the climate-control system's delivery of heating and cooling. Input data for the calculation method include building data, characteristics of the occupying organisation, and data relating to the climate-control system.

METHODS

Excessive energy consumption occurs during the 40% period when 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 3 shows the standard heating cooling curve for an AHU. Figure 4 shows the same building related energy profile with the effect of the standard curve.

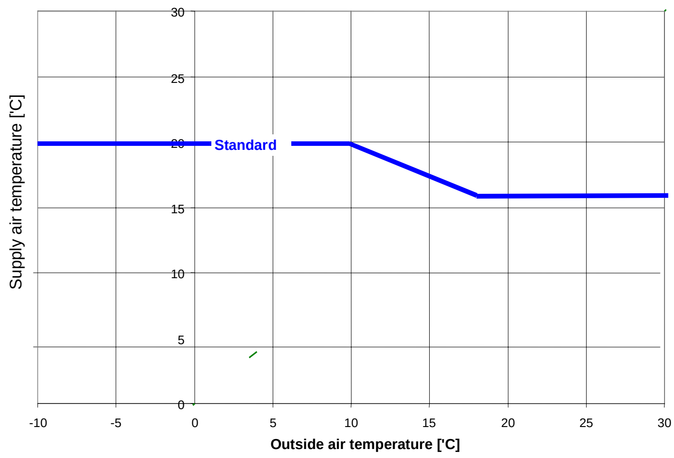

Figure 3. Standard heating/cooling curve for AHU

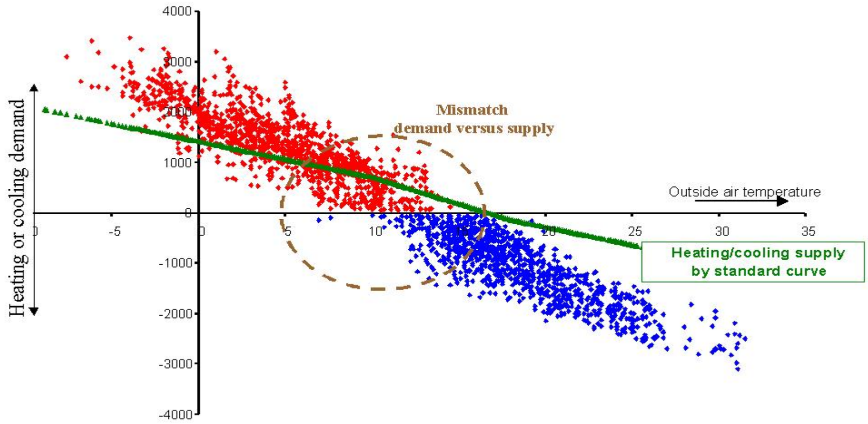

Figure 4. Energy mismatch due standard heating/cooling curve.

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The heat load profile, for typical Dutch conditions, for a whole year is presented in figure 5. The figure shows that a limited number of hours the HVAC system works in Full load conditions.

The design of a energetically optimised heating cooling curve, which can match the demand with the supply, decreases the energy consumption with a maximum of 35%.

How does the design method work?

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. It is also possible to use a simplified design method. This method is published in the Dutch ISSO publication 68.

The method is briefly broken into five major steps, see Figure 6. shows these 5 major steps.

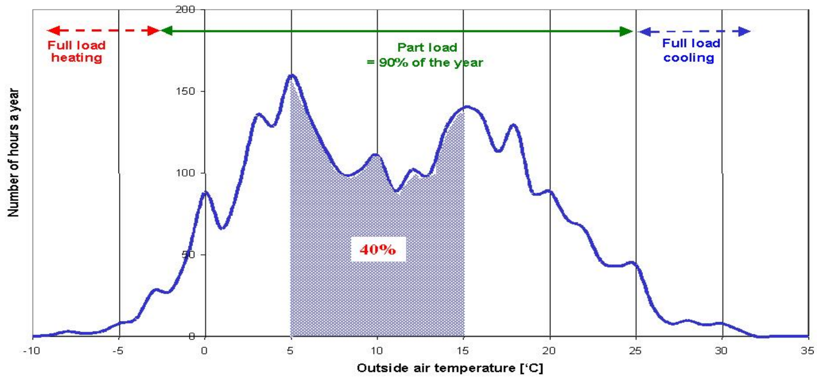

Figure 5. HVAC load profile over a year time

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 VA 114.

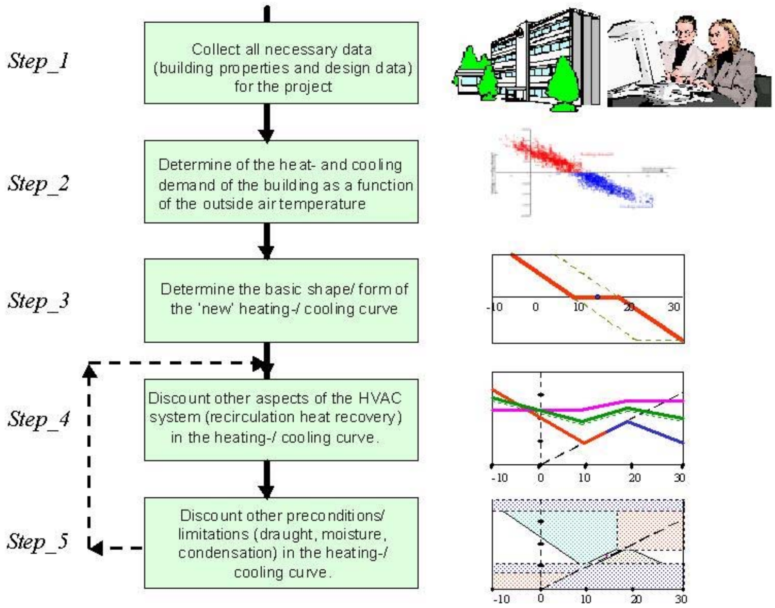

Figure 6. The main 5 steps to design the heating/cooling curve

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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; and 3) the building user.

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.

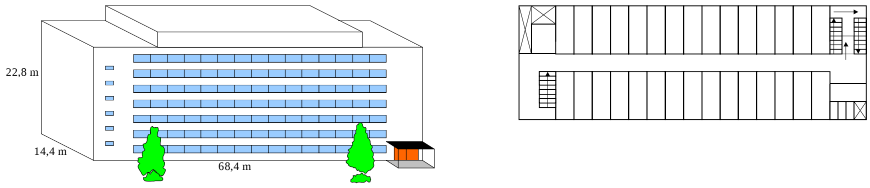

Figure 7: The ground plan and the façade of the selected building

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

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.

Figure 8 shows a typical building heating and cooling demand profile. The demand for heating and cooling at the same time occur at 40% of the time.

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. Step 3 consist the following actions:

- Determine of the turn-over (free) temperature of the building;
  (Note: The turn-over temperature is the temperature where no heating and cooling is required).
- Calculation of the transition range, that means the temperature interval for the outside temperature in which either heating or cooling demand may exist;
- Investigate the sensitivity of the heating and cooling demand in relation to the outside air temperature;
- Determine your principle choice of HVAC installation;
- Split the required capacity into a part for the central AHU and for the individual room systems;
- Determine the basic shape of the new heating/cooling curve;
- Redraw the basic shape as a function of the supply air temperature.

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Determine the turnover (free) temperature and transition range
In general, when the outside temperature is equal to the "Turn over temperature" (figure 9), no heating or cooling demand exists within the building. This is also called 'free temperature' of the building. That means, no heating or cooling is supplied to the ventilation air.

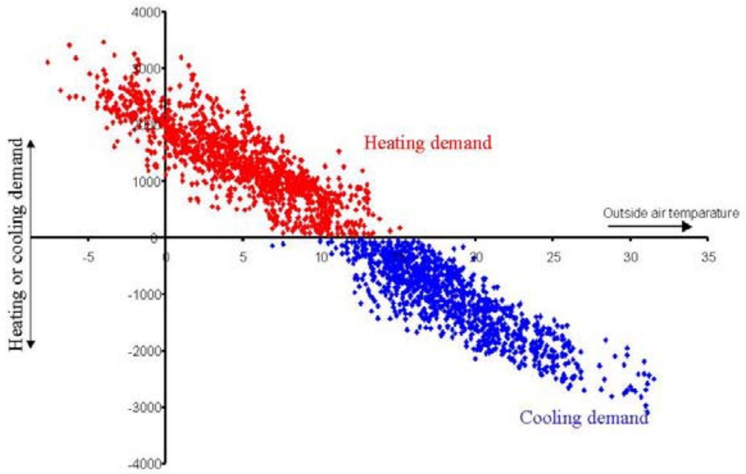

Figure 8. Heating and cooling demands over a year period (data points per hour)

The transition range (figure 9) can be defined as the temperature interval for the outside temperature in which either heating or cooling demand may exist. No heating or cooling is therefore added to the supply air.

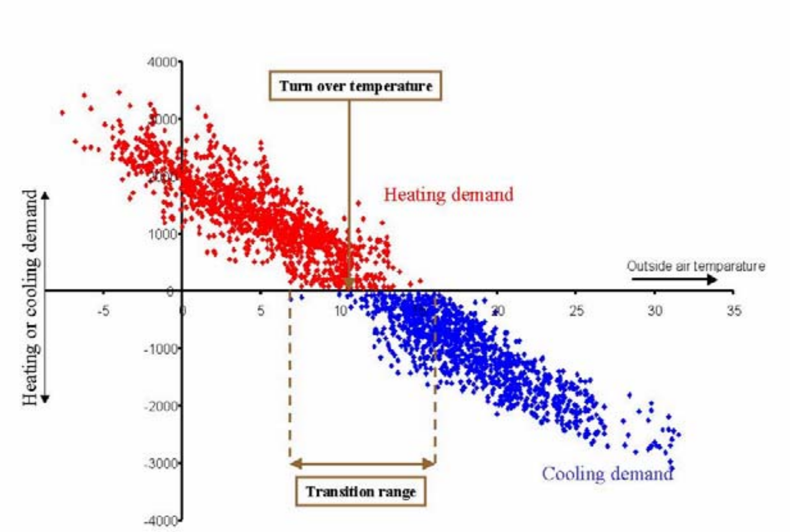

Figure 9: Determination of the Turnover temperature and transition range

Determine your principle choice of HVAC installation
The designer has to make a principle decision about the type of HVAC system to match the heating and cooling demands. In our sample the choice is made for a central AHU with a local 4-pipe induction unit system.

Split the required capacity into a part for the central AHU and for the individual room systems
In the sample the choice was made to make maximum effort from the free heating/cooling condition. This means that the air supply temperature only follows the outside temperature dependency and will contribute for a small part for the required heating or cooling demands. The local units will contribute for the remaining part of the demands and are able to match with room differences through their individual control possibility.

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Determine the basic shape of the new heating/cooling curve

When there are two supply (transport) media available, the basic shape of the heating/cooling curve for the AHU will look like the yellow line in figure 10. If there is only one supply media available the basic shape of the heating/cooling curve is shown in figure 11.

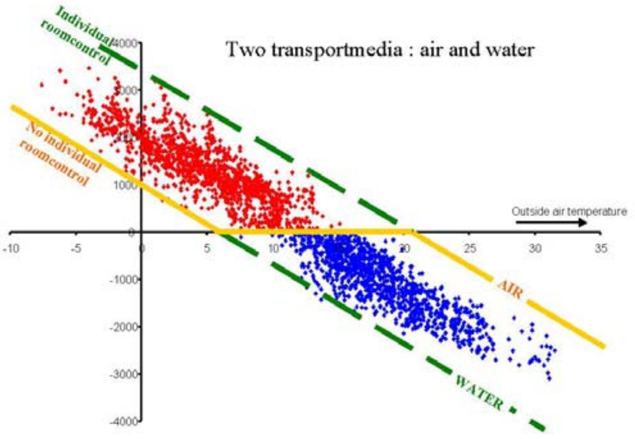

Figure 10. The yellow line is the basic shape for the new heating/cooling curve of the AHU

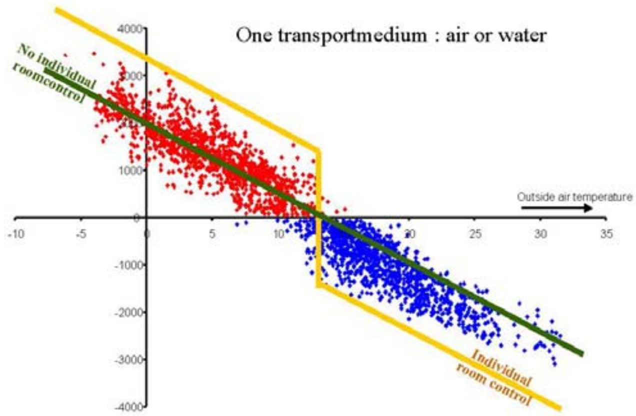

Figure 11. Basic shapes of the heating/cooling curve if there is only one media available

Redraw the basic shape as a function of the supply air temperature

In view of the fact that the heating/cooling curve is not expressed in temperature differences but in actual temperature levels, the desired heating and cooling must be added to the outside temperature. This is shown in figure 12. The dotted line is the Y=X line, which means that the base is equal to the outside temperature. To add the desired heating or cooling the basic form (see figure 10) is added to the Y=X line.

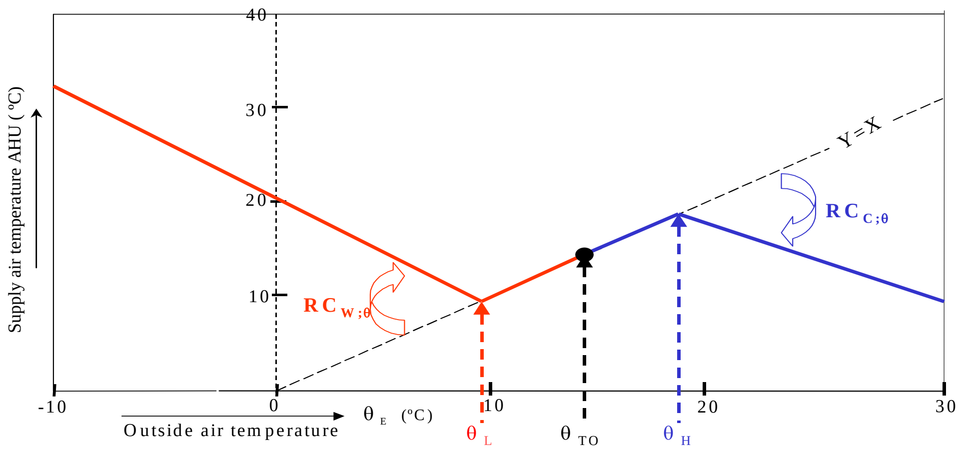

Figure 12: The basic shape of the heating/ cooling curve

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)
- Recirculation (affects the temperature level of the heating/cooling curve).

Figure 13 shows the influence on the basic shape when the effect of recirculation of the exhaust air is taken into account.

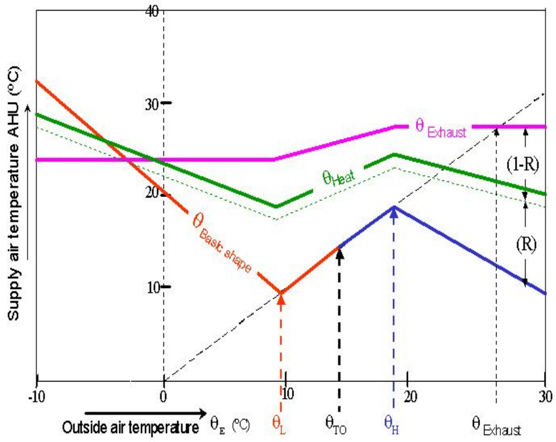

Figure 13: The effect of recirculation of the exhaust air (purple line) is taken into account. The basic shape is changed into the θ heat, the green line.

Heat recovery

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 energetic effect of heat recovery and the areas in which this should be operated is shown in figure 14. 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.

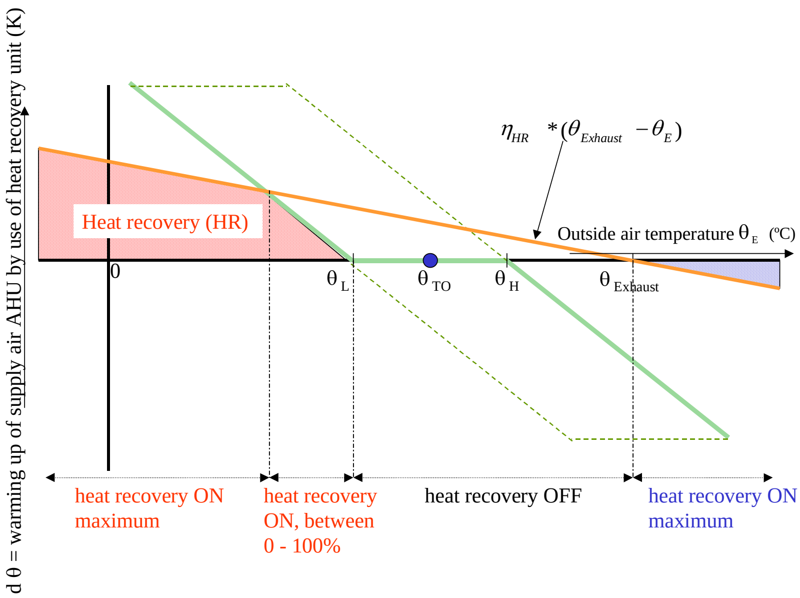

Figure 14. Operating strategy for heat recovery systems

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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 15 shows the boundaries of different risks related to the heating/cooling curve.

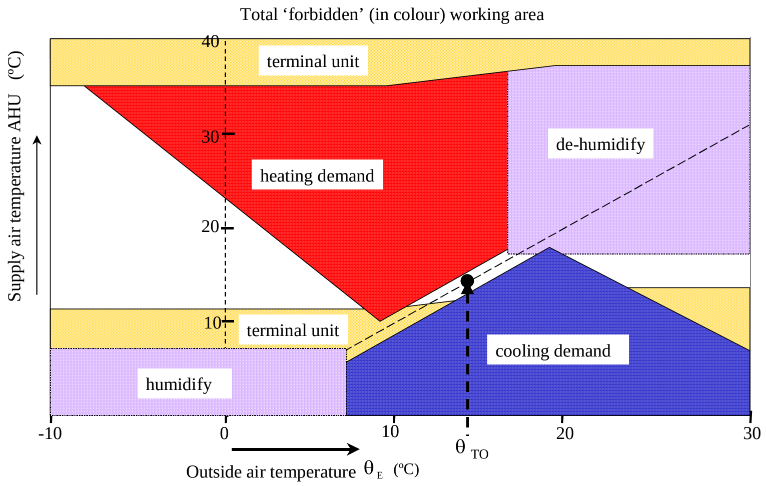

Figure 15: Boundaries limit the freedom of design

RESULTS

The result of these 5 steps is the energetically optimised heating/cooling curve as shown in Figure 16.

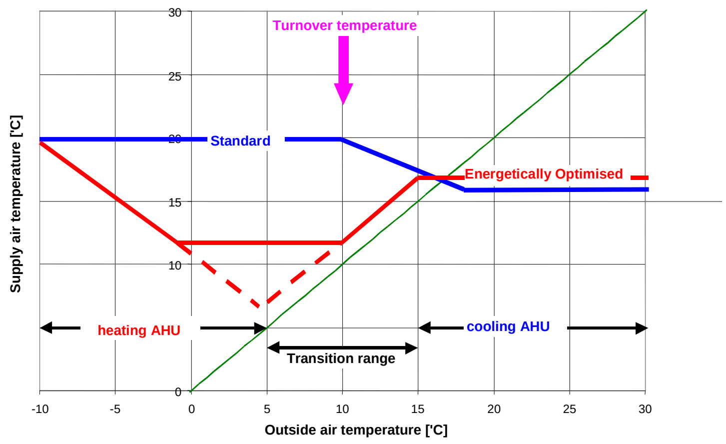

Figure 16. An energetically optimised heating/cooling curve Energy saving

Energy saving

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 (see Figure 17):

- 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/m^2 N.E.) is occupying the same sample building, the energy saving is even higher (36 % for heating and 19 % for cooling).

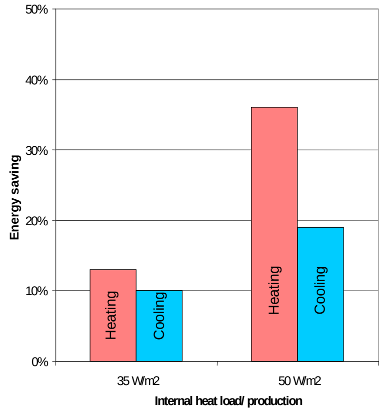

Figure 17. Energy saving for heating and cooling

Improved comfort

The comfort improvement is showed in Figure 18 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. 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.

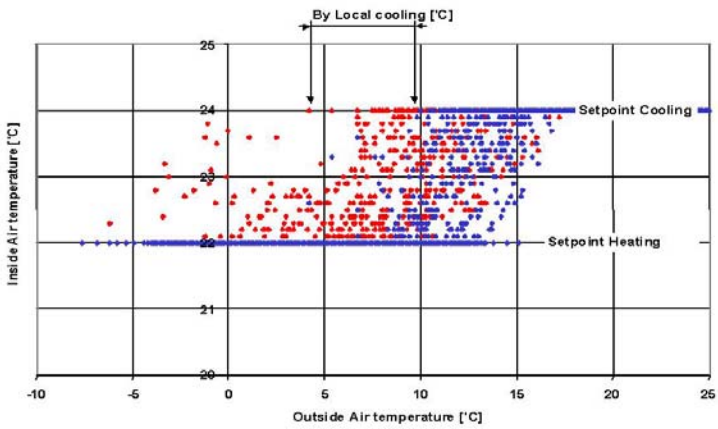

Figure 18. Improved comfort through adjusting the heating /cooling curve

RESULTS OF THE RE-TUNING OF THE HEATING CURVE IN REAL PRACTISE

In 2003, new (5) and existing (4) office buildings were selected for checking (i) the existing use of the building in relation tot the original design, (ii) the current set points of the heating curve of the central Air Handle Unit (AHU), (iii) complains of the users, if applicable and (iv) the internal heating load.

Based on this information, the 'optimised' heating curve were calculated for the specific building as described in this paper. The outcome of the calculations was that for all the buildings new set points were found. The heating curve of the central AHU were re-tuned based on the new set points.

In the begin of 2003 a simple monitoring program were started for checking the effect of the new heating curve. The results of these exercises were available at the begin of 2004.
The results of the "re-tuning" exercises are presented in table 1.

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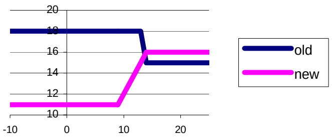
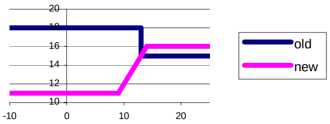
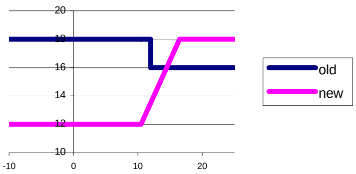
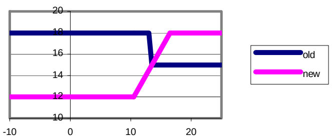
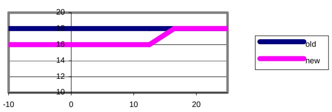
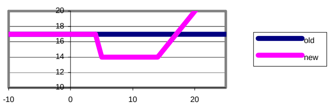
Building	Set points	Energy saving	Specifications
	 local set point heating : 22.5 C local set point cooling : 24.5 C	Heating : 12 % Cooling : 33 %	Internal load : 45 W/m ^{2} GFA : 20,500 m ^{2} Occupation: 825 persons HVAC : Constant air volume system with local convectors with fans in the zones. (Gross Floor Area (GFA))
	 local set point heating : 23.0 C local set point cooling : 24.5 C	Heating : 22 % Cooling : 35 %	Internal load : 46 W/m ^{2} GFA : 28,800 m ^{2} Occupation: 1200 persons HVAC : Constant air volume system with local convectors with fans in the zones
	 local set point heating : 22.5 C local set point cooling : 24.5 C	Heating : 15 % Cooling : 20 %	Internal load : 62 W/ m ^{2} GFA : 12,000 m ^{2} Occupation: 850 persons HVAC : Constant air volume system with local convectors with fans in the zones
	 local set point heating : 22.5 C local set point cooling : 24.5 C	Heating : 25 % Cooling : 28 %	Internal load : 44 W/ m ^{2} GFA : 23,500 m ^{2} Occupation: 950 persons HVAC : Constant air volume system with local convectors with fans in the zones
	 local set point heating : 22.5 C local set point cooling : 24.5 C	Heating : 12 % Cooling : 25 %	Internal load : 43 W/ m ^{2} GFA : 105,000 m ^{2} Occupation: 3,500 persons HVAC : Constant air volume system with local convectors with fans in the zones
	 local set point heating : 22.0 C local set point cooling : 24.0 C	Heating : 10 % Cooling : 10 %	Internal load : 40 W/ m ^{2} GFA : 6,735 m ^{2} Occupation: 600 persons HVAC : Constant air volume system with local radiators and cooling in the ceiling.

Table 1. The buildings were the heating curve of the central Air Handling Unit (AHU) were re-tuned.

CONCLUSIONS

- The method described in this paper shows the serious need of an optimal tuning of heating/ cooling curves in HVAC systems;
- The method described in this paper shows how to use heat recovery systems and recirculation of the exhaust air in the right way and how they should be controlled and taken into account;
- Use of general common (standard) heating/ cooling curves can lead to many complaints of comfort and to high energy consumption;
- 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 <u>expected</u> energy saving of 5 – 35 % in relation with common heating curves;
- In real practise, the effect of retuning of the heating/ cooling curve of the central AHU on energy savings is in the presented buildings for heating between 10 – 25 % and for cooling between 10 – 35 %;
- The full benefits of this method will only come to account if the HVAC system is proper hydraulically and air balanced.

ACKNOWLEDGMENTS

This project was a co-operation between ISSO, TNO Building and Construction Research (TNO Bouw) 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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A detailed description of the method can be found in the Dutch ISSO publication 68, "Energetically optimised heating and cooling curves". The publication (Dutch language) can be ordered by ISSO. http://www.isso.nl/

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