Ingenieurbüro
für Energieberatung
& Gebäude- und
Anlagensimulation

Use of Hourly Energy Analysis Software for Energy Design Optimization.

by

Guido von Thun

Abstract

The purpose of this paper it to show how further fields of energy optimization emerge through the use of modern, powerful computers and corresponding software packages. It is demonstrated which influences have a major part in the energy consumption of buildings. It is explained how by means of effective simulation programs, phenomena like the thermal inertia of the building can be used to influence the sizing of systems and components. It is shown that very exact calculation methods are necessary to get results which provide valuable data for the optimization of energy consumption. A further benefit can also be a possible reduction in the size of the HVAC system which leads to lower investment costs.

Keywords: Air Conditioning
Energy Conservation
Heating
Load Calculation
Sizing

GvT Ingenieurbüro für Energieberatung & Gebäude- und Anlagensimulation
Nürnberger Straße 61 . 90762 Fürth . Telefon 0911 - 530 15 01 . Telefax 0911 - 530 15 02
info@gvt-consulting.de . www.gvt-consulting.de

Use of Hourly Energy Analysis Software for Energy Design Optimization.

by

Guido von Thun

Abstract

The purpose of this paper it to show how further fields of energy optimization emerge through the use of modern, powerful computers and corresponding software packages. It is demonstrated which influences have a major part in the energy consumption of buildings. It is explained how by means of effective simulation programs, phenomena like the thermal inertia of the building can be used to influence the sizing of systems and components. It is shown that very exact calculation methods are necessary to get results which provide valuable data for the optimization of energy consumption. A further benefit can also be a possible reduction in the size of the HVAC system which leads to lower investment costs.

Guido von Thun is Consultant, Nuremberg,FRG

Introduction

First of all Energy Design Optimization has to be defined. In the past buildings and system design was mainly governed by construction costs and the aim to operate systems properly. This is according to engineering the least sophisticated approach. There was no need to emphasize reduction of operational costs. So rather simple calculation techniques to more or less estimate heating or cooling load were used.

During the Energy Crises energy consumption was not only a matter of price but also a matter of availability of energy. This led to all kinds of ideas on how to do energy conservation. Following the fundamental to solve problems where they arise building and system design was thought about newly. Subsequently, engineering efforts were spent on calculation algorithms in order to find exact load results. To evaluate different designs and do case studies highly sophisticated tools were necessary.

These efforts led to hourly simulation programs which nowadays are available to everybody. The main differences of these tools will be worked out in this paper. In order to do an appropriate comparison of the methods I will first do a discussion on essential items of loads and energy calculation.

The evaluation of heating and cooling loads and energy consumption is mainly due to

- environmental conditions such as outside temperatures, solar impact, wind speed influence, infiltration.
- internal loads such as people, lighting, equipment.
- material dependant conditions such as thermal conductivity, surface roughness.
- architectural design by fraction of glazing, orientation of the building, shading devices, etc.

All of these items except the solar impact are evident in most calculations techniques.

If peak loads are calculated conventional methods lead to satisfying values when considering heating loads. For cooling loads approximations for solar impact on walls and solar radiation through windows are made.

Film reflections for the later are considered in a poor manner. Most algorithms take only one angle of incidence into account, others three.

Infiltration influences are calculated at design conditions. This all together leads to the baseline demand.

One of the main components is suppressed in most conventional calculation methods. It is the thermal inertia. The effects of this phenomena are still weighted by factors which are set on top of the loads results. In fact the effects of thermal inertia produce what could be called the dynamic portion of loads.

It ist easy to understand when looking at a heavy weight construction. Time need it to heat up to defined comfort conditions can be rather long. In extreme situations two to three days. On the other side the same time is needed to cool down. The time period is dependent on

- the temperature difference

- the installed capacity of the heating and cooling source

- the mass of the building

- other internal or external loads.

These dynamic loads usually are the dominant loads as changes in temperature levels require change of loads. To meet the fast load changes systems will run through transinient conditions. Subsequently for a rather short period of time the components in the plant will be in full operation. Looking at the average load during these periods the Coefficient of Performance will decrease strongly. Hence energy supply for utility will rise.

Taking the conclusion from the foresaid one of the mayor design goals should be to have smooth load curves. No peaks would be desirable-small peaks are realistic. Furthermore smooth changes in loads should also be the result of the design.

To fulfill all the requirements tools which model the thermal behavior of buildings as exact as possible are necessary. These tools must lead to accurate results mainly during the occurrence of part loads.

Complexities of Building loads Calculations

As mentioned before, there are different influences whose causes are of different source. There is no doubt that weather conditions such as outside temperature, wind velocity, solar radiation can be considered as the main influences for baseline loads. For the geographic location of each building, however, these have to be seen as constant factors and normally can not be influenced.

The corresponding architectural design of a building, though, can influence these considerably. Obviously, temperature effects can be influenced by building constructional design. This refers especially to the configuration of perimeter walls and the proportion of window surface to the external walls. As the windows naturally represent a weak point for the heating loads, special attention has to be paid to their constructional design. As for the windows, the same can be said concerning the load factor of the cooling system. Referring to the latter, apart from the pure U-value, the transparency and the reflectance are also features which have considerable effects on cooling load. Windows have a special importance, as those qualities which are undesirable in summer (high transparency, subsequently a higher energy transmission through the windows) do have a desired side-effect to lessen the heating loads in winter, though. That is to say, for the optimization of the architectural design of the building one has to find solutions, which represent the best possible compromise of seasonal influences.

Further influences on the loads resulting from the surroundings are wind velocity and the subsequent infiltration through gaps. These loads, however, are the result of desired or undesired openings in the external surface of the building. Therefore they can only be included to a small extent in the energy optimization. For the calculation of their influences on the loads effective algorithms are necessary, because the dynamic pressure of the wind changes with the square of its velocity. The dynamic pressure, however, is the decisive factor for the infiltration quantity. For the calculation it is of no importance whether infiltration loads are caused by open windows or defective construction of the façade.

A further basic load factor is the orientation of the building and architectural measures such as shading devices will not be discussed in length here. There were innumerable publications on this theme in the past. It is just mentioned for the sake of completeness.

For this discussion it is essentially necessary to take the loads caused by occupancy into account . These such as all loads already mentioned only appear at certain times and in different quantities. The most important are thermal loads through occupancy by persons, electrical equipment and illumination. Of course, these loads increase the cooling load in summer and decrease the heating load in winter.

All the influences on the loads mentioned so far only present themselves at different times. Partly they have to be added to one another, for example solar radiation and internal electrical loads, on the other hand they compensate each other, for example the reduction of the heating load by all the internal loads. So, for the calculation of the building loads, mainly variations in time of the loads have to be considered. When considering individual loads the time of occurrence consideration has to be indicated, too. Usually, conventional calculation methods determine the maximum load in the case of heating or cooling. With this value the systems design can be carried out. It is obvious that this necessarily leads to considerable over dimensioning in individual cases.

Then, however, a factor is neglected, which is important but had been disregarded in the past. It is the thermal building inertia.

Parting from the fact that a room is kept at a constant temperature the thermal building inertia only has the effect that the changing external and internal influences show after a certain delay. The heating and cooling loads will become apparent later in dependence on the inertia of the building. It is not difficult to see that a building with a heavy construction implies longer delays than a building with a light structure. In the case of a light steel construction all the external and internal influences will have direct effects on the loads. A heavy structure (e.g. concrete dug-outs) will not be affected by short-term changes of influences. This is quite obvious and everybody knows this effect from everyday experience.

The Advantages of Hourly Simulation Programs

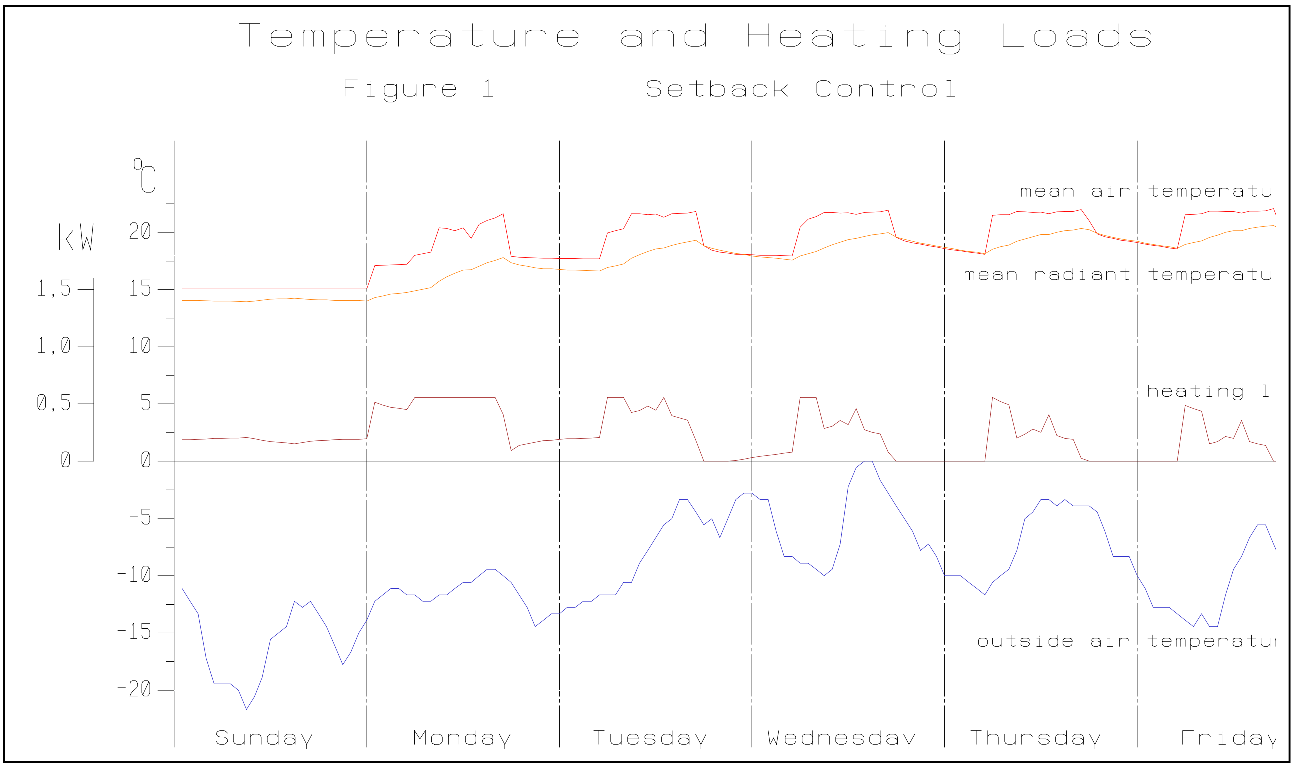
Innumerable calculation programs which comply with the conventional calculation methods (according to ASHRAE or other national standards) are available on the market. It has to be underlined that these are above all normative specifications which state minimum requirements for the design. All the existing standards and the calculation programs based on them do not claim physical exactness. As long as only the determination of peak loads is concerned the algorithms used are sufficient for average buildings. It is, however, more than doubtful to try to deduce from these algorithms developed for the calculation of peak loads anything about energy consumption during longer periods e.g. one year. It has turned out that most of the methods lead to high inaccuracies when calculating energy sums over a longer period of time. Especially relevant parameters are only insufficiently taken into account. When establishing prognostics with these methods and additionally implying average values for e. g. for outside air temperature deficient results are evident. Transient behavior as also major influences such as solar radiation and control strategies are likewise neglected.

For this reason special simulation programs were developed. These make allowance for transient processes. They are based on the nowadays well-known physical correlations which are used in very exact models. Therefore, in these calculation programs increasingly longer periods of time are calculated. The time intervals for these calculations generally are one hour steps which represents a sufficiently exact resolution in respect of the inertia of a building. These tools offer the possibility of a design optimization. This means reaching the highest possible effect on thermal comfort by the lowest possible expenditure of investment and consumption.

Method of design optimization

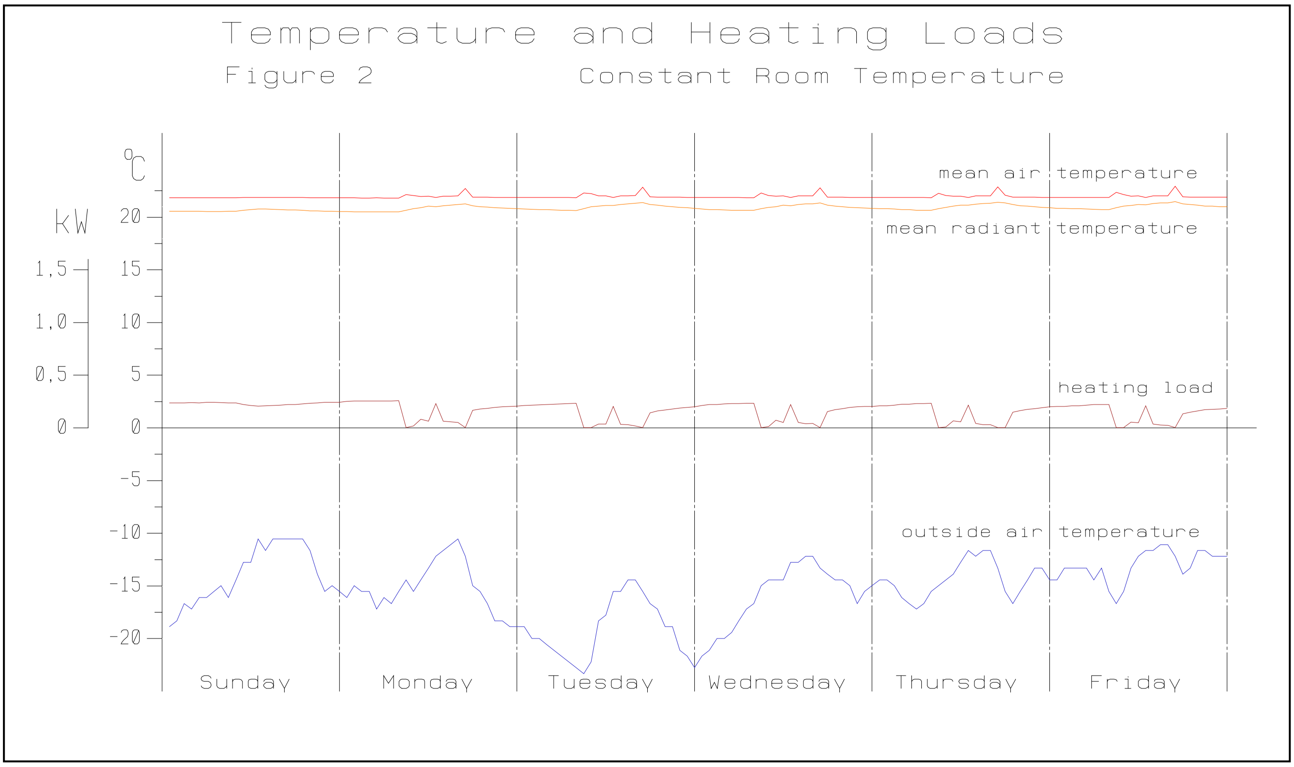
In the following a possible approach of design optimization is illustrated. This method has been repeatedly applied with success and proved its worth in practice.

The above mentioned referred to a constant room temperature. When changing the room temperature e.g. by a set-back during night-time the cooling and the reheating process of the room introduces a transient component into the calculation of the loads. This will be illustrated in the



following example.

Figure 1 shows the temperature and heating load course of a section of a building with heavy weight structure which is used as an office. The bottom graph represents the course of the external temperature. Above it is the course of the heating load for this section. The two upper graphs represent the mean air temperature and the mean radiant temperature. The building was equipped with a control system which lowered the room temperature to 15°C at weekends and by night. Subsequently the mean radiant temperature dropped to approx. 14°C at night. If the heating system was already turned on on Monday at midnight an air temperature of approx. 20°C could be reached when office hours started, the mean radiant temperature, however, amounted only to 16°C. In the course of the day the mean radiant temperature does not exceed 17.5°C. In the evening hours the set-back program starts again so that only a small amount of energy is being supplied. The next day (Tuesday) the mean radiant temperature reaches only by noon the value of 18°C which is necessary for comfort. Only on the third day (Wednesday), already in the morning hours a temperature level can be taken for granted which guarantees comfortable conditions in the rooms. It is remarkable that during this time the external temperature by day did not drop below -15°C. The heating load course presents the peaks which are typical for set-back by night and normally appear during morning hours. These comparatively high peak loads of approx. 500 to 600 Watts naturally have to be supplied by the systems and the central plant. This leads altogether to a correspondingly high capacity for supply. Out of the peak heating periods especially when

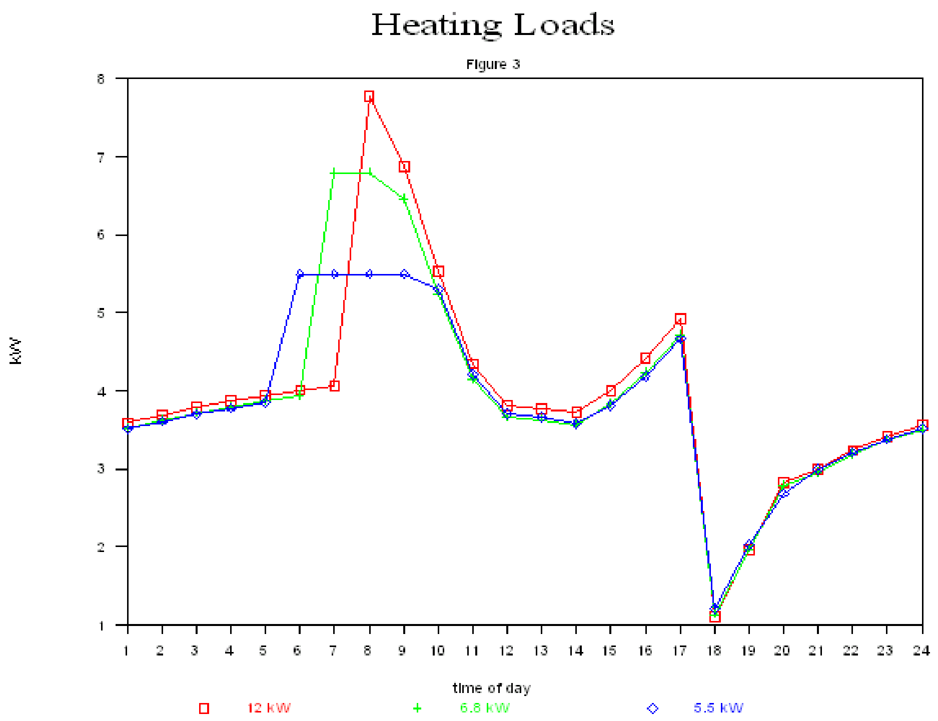


It was tried to solve the problem of the insufficient thermal comfort in the morning hours or after longer set-back periods by other control strategies. Figure 2 shows the effect if there is no drop in temperature. The heating load course graph is very well balanced and shows a generally constant quantity with the exception of office hours during the week. The temperature courses of the room air and mean radiant temperature are also very well balanced. The temperature levels are within a range which can be considered as sufficiently comfortable. It is especially striking that the heating power course shows no peaks. The consequence is that the systems and the central plant have to supply less peak load. Apart from that the components are operated in a favorable working condition which results in a good Coefficient of Performance.

It can be seen from this example that it is necessary for the determination of the supply of power as well as for the energy consumption to consider longer periods of time. In contrast to the conventional calculation methods, this requires a new approach. It must not be anymore the sense and purpose of a heating or cooling load calculation to determine a value from the existing data specific for the building without at the same time defining a control strategy together with the calculated value. As shown above this is especially necessary in order to obtain a load as good as possible of the components which supply the building with energy. This is especially valid because all the components as boilers, chillers etc. have a bad Coefficient of Performance when working at partial load and thus have a higher energy consumption.

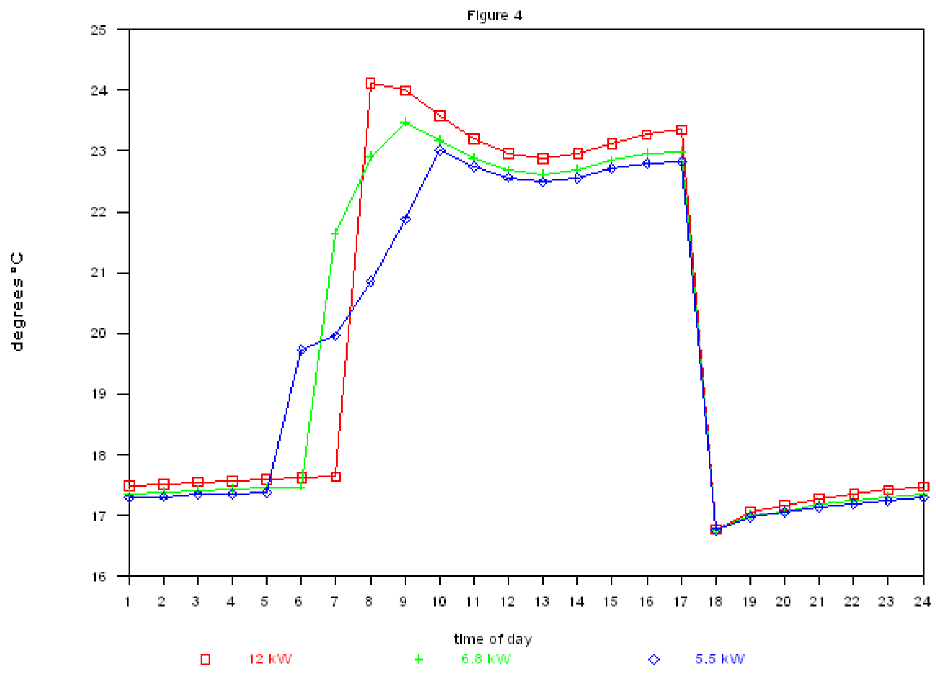
The basic idea is to eliminate all load peaks as far as possible. Therefore a method of iteration is used by means of simulation programs; it guarantees a load splitting as uniform as possible. In this way all components which are susceptible to influences are included. This means as far as it is still possible or if there is any possibility of exerting influence the architectural design is also taken into account. The optimization of the architectural design can only be carried out by simulations of the yearly energy consumption. The models used for this purpose have to be as realistic as possible. For a building with windows with reflective films, for example, one has to rate a higher need of electrical energy in its calculation than a building with clear panes. Because of the reduction of solar radiation especially in the twilight hours and with heavy clouds the illumination in the buildings will be switched on. So a part of the economizing effect for cooling resulting from reflective films is compensated again because of the higher consumption of illumination energy.

In the field of architectural measures there exist a host of possibilities which result in a reduction of energy consumption. These should be carried out first in order to reach a low energy consumption specific for the building. After optimizing all the measures such as insulation, design of the facade, shading devices and other energy saving measures the basic preconditions for an economic operation of the building are established. The next step consists in optimizing the control strategies in the individual rooms and sections. For this purpose one has to establish marginal conditions of thermal comfort depending on their use. Office buildings are usually occupied from 8 a.m. until 5 or 6 p.m. That means during this period the comfort conditions should be sufficient. In other words the air temperature should amount to about 21°C in the case of heating and not exceed 26°C in the case of cooling. In the case of heating it is of vital importance that the mean radiant temperature is not lower than 18.5 to 19°C. When running systems with set-back operation it is important to reheat the building in time. Figures 3 and 4 show different heating load curves after a set-back period during the night and the corresponding temperatures.



The graphs indicate that the thermal comfort when starting work in the morning can be guaranteed by either an excessive heating during a relatively short period of time or by preheating in time. It can also be clearly seen that the power to be placed at disposal is reduced in dependance of the preheating period. By an adequate synchronization of the power placed at disposal and the preheating period it is possible to carry out a minimization of the peaks during the heating-up period. It is

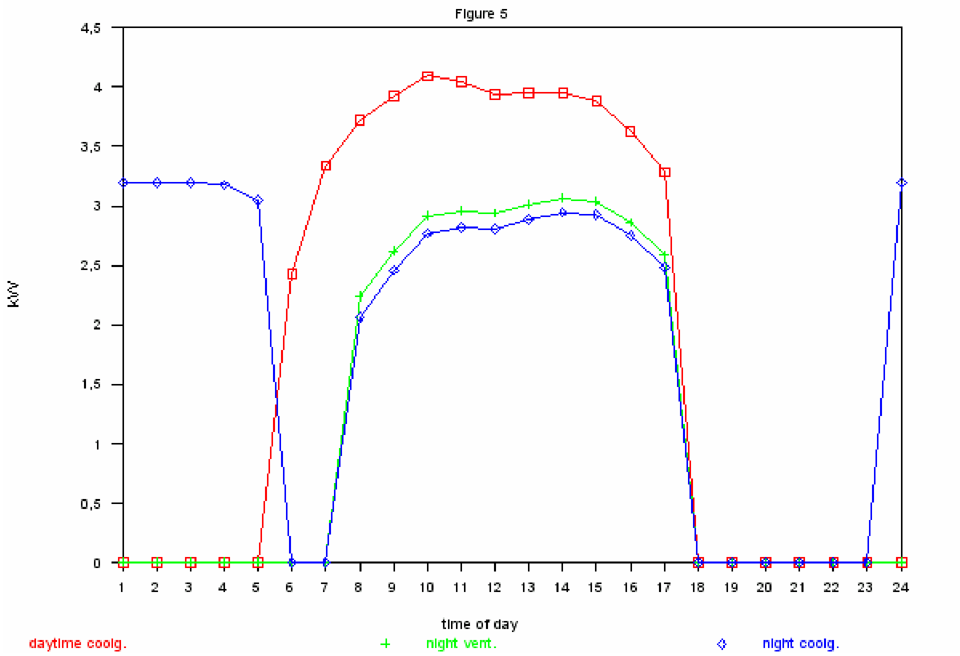
Room Air Temperatures



evident that the saved power to be placed at disposal naturally does not have to be effectuated in the form of investing in components.

The facts referring to the case of the heating load also apply to the case of the cooling load though of course the approach is slightly different. In the case of the cooling load the ranges of tolerance allowed for the admissible maximum air temperature are very important. If in the case of computer rooms, for example, there is only allowed a deviation of less than 1°C there is hardly any possibility for optimization. Should, however, such as in office rooms a variation of temperature (e.g. from 21°C in the morning to

Cooling Loads

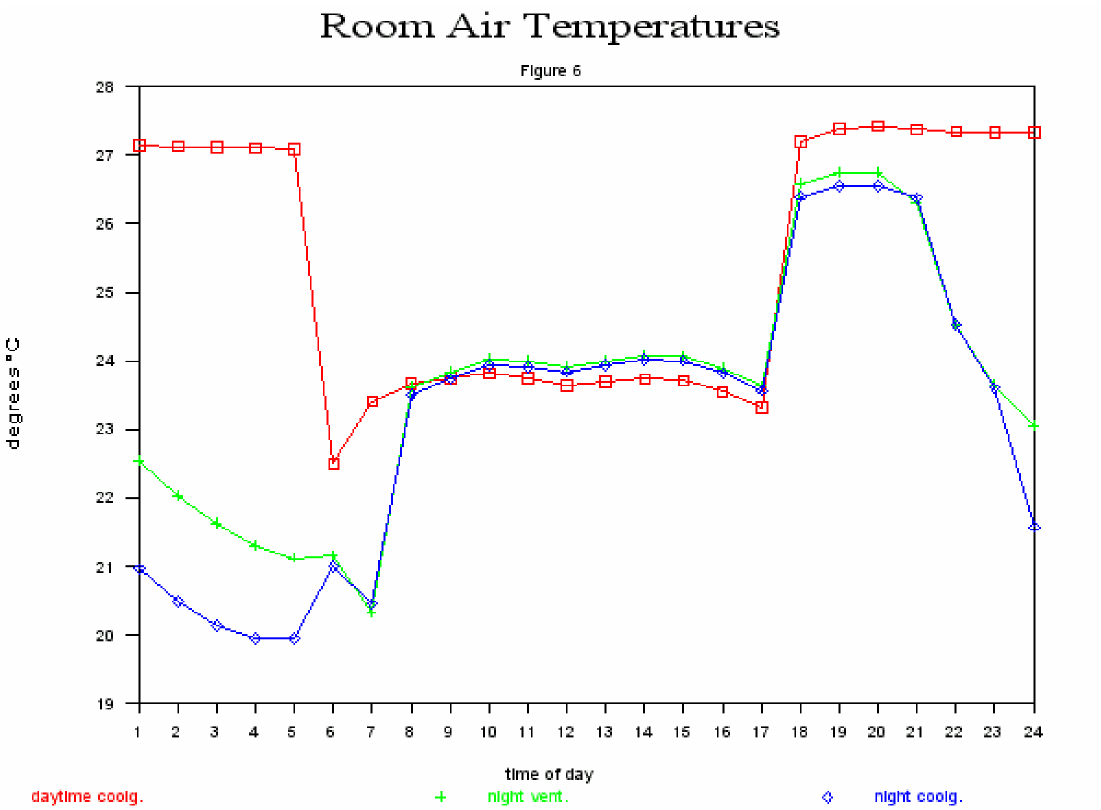


26°C in the afternoon) be admitted there are possibilities of optimization. These are represented in the figures 5 and 6.

The first graph shows the thermal behavior in a room whose cooling system starts in the morning and operates during working hours with the corresponding loads. At night the systems do not operate.

The second graph shows represents the same room with systems operating at night without active cooling. That is to say unconditioned external air is used to cool the building mass during the night. The main point of this concept is to abduct the warmth accumulated in the building at a low cost. Of course this is only possible if the external temperature is correspondingly low during the night and in the morning hours.

If this should not be the case, such as on very sultry and warm summer



days, a nocturnal cooling of the building can be effected also by active cooling, that is to say by means of chillers. This is economical in two ways as on the one hand the electrical rates are lower at night than during day-time and on the other hand the coefficient of performance of the chiller or cooling-tower respectively is much higher. This is shown with the third graph.

If a uniform section load temperature process has been achieved there are effects on the systems control. As the supply air temperature, seen in absolute terms, in this case does not have to be as low as in conventionally planned systems the cold duct temperature does not have to be lowered so much. A dehumidification will now only take place if really intolerable conditions arise. During the temperate seasons a great part of the supply air is not or only sensible cooled.

Conclusions

Obviously this concepts are based on the fact that the thermal building inertia is used here in order to shift the peak load.

The advantage of the above mentioned not only consists in having to cover reduced heating and cooling loads but also in the fact that the supply air volume can be smaller. This means consequently smaller duct sizes and smaller components. Both result in lower investment costs. Another factor is that to meet lower loads smaller temperature differences between supply air temperature and room air temperature are sufficient. This contributes considerably to the thermal comfort. The rate of complaints in thus optimized systems is very low.

It goes without saying that all loads which the systems do not have to cover naturally do not have to be supplied by the central plant. Lower investment costs are also a consequence as the equipment size quite often is 30% to 50% lower than that of a conventional system. In this context I should like to refer again to the point mentioned at the beginning that though components thus dimensioned have a longer operating time during one year, they work, however, at such operating points which allow a considerably higher coefficient of performance. Subsequently the operating costs of thus dimensioned components are much lower in spite of the absolutely longer operating time.

It should be emphasized that only detailed hourly simulation tools provide the means to do sophisticated design optimization. It should become state of the art in HVAC design works.