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Energy-efficient retrofitting of office buildings

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Abstract

A number of energy-saving retrofit measures are simulated on a base-case building situated in Stockholm, Sweden. The base-case building is modelled on an existing building, and data for the thermal resistance of the building envelope as well as data for internal heat gains, are derived from the actual building. The retrofit measures studied range from single measures carried out on the HVAC system or on the building envelope, to combined measures carried out on the HVAC system and the lighting system simultaneously. Sensitivity analyses using an alternatively designed base-case building, have also been carried out. The simulation results show that substantial energy savings can be achieved.

Keywords: Energy savings; Retrofitting measures; Office buildings

1. Introduction

This article is based on selected parts of a report in the CADDET Analysis Series [1]. CADDET (Centre for the Analysis and Dissemination of Demonstrated Energy Technologies) is an international network sponsored by 14 International Energy Agency (IEA) countries which develops, analyses and exchanges information on demonstrations of energy-saving technologies for all end-use sectors. The CADDET Analysis Support Unit (CASU) carries out analyses for CADDET regarding energy technologies in buildings and industrial processes.

All office buildings need to be refurbished during their lifetime, often more than once. The comprehensive nature of many refurbishments is a response to a number of factors, including the normal ageing process of the building and its equipment, changes in the requirements of building occupants, and the development of new technologies which offer advantages justifying the replacement of those already operative in the building. Although energy efficiency is not usually the prime motive for major refurbishment, a project of this type does offer opportunities for substantial energy-related improvements. Whether or not energy-saving measures are retrofitted during the refurbishment of office buildings depends on two important issues:

- levels of current energy use, as determined by an energy audit;
- reliable estimates of likely future savings.

This article focuses on the latter issue. It examines various energy-saving measures that can be retrofitted to existing buildings and, using simulation techniques, it assesses the effectiveness of those measures in reducing energy consumption. During the simulations, various retrofit options have been compared to a base-case building. The same retrofit measures have also been carried out for an alternative base-case building.

From an energy point of view, building performance is quite complex. This is particularly evident in office buildings where the thermal interactions between the building structure, the indoor air, internal heat loads and solar radiation result in continuous fluctuations in heat surplus or heat deficit.

The complexity of the energy balance often makes it quite difficult to produce reliable estimates of the compound effect of a certain measure or combination of measures. In order to avoid one-sided assessments, any analysis of the effect of energy conservation measures must be based on the total energy balance of the building. That energy balance consists of three main components:

- the degree of control of the building's climate that is achieved by the heating, ventilation and air-conditioning (HVAC) system;
- heat generation within the building;
- heat flow through the building envelope.

The retrofit measures studied have been carried out within each of these three main energy balance components. A presentation is given below of the building which has been used as the base-case building. Then

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a description is given of the applied retrofit measures examined and, finally, the results of the study are presented together with a discussion. Together with the final results, an alternative base-case building is described and the results obtained using this as the base-case building are presented and compared to the results obtained for the original base-case building. Carriers's Hourly Analysis Program (HAP), version 2.02, has been used for all simulations.

2. Base-case building

The building chosen as a model for the base-case building is an existing building [2]. The retrofit measures studied in this paper are based on retrofit measures identified in a number of demonstration projects and presented in Ref. [1].

2.1. Climate

The base-case building is situated in Stockholm, Sweden, which has a climate as described in Table 1 and Figs. 1 and 2.

2.2. Walls, roof and windows

The building layout and orientation is shown in Fig. 3. It comprises eight floors and has a total floor area of approx. 15 700 m^2. Room height is 2.7 m. Each floor is an open-plan office, with both personnel and office equipment evenly distributed over the floor area.

The building which, from a heat storage point of view, is regarded as being of heavyweight construction (high heat storage capacity), has light-coloured exterior walls with an average U-value as high as 1.6 W/m^2 K. The roof is dark and has a U-value of 0.7 W/m^2 K. The windows are of double-pane, bronze-plated, heat-absorbing/reflecting glass. This type of window has a U-value of 2.1 W/m^2 K and a shading coefficient of 0.4. The air infiltration rate is 0.24 air changes per hour (or 0.18 l/s m^2 floor area) throughout the year.

2.3. Internal heat gains

The internal heat gains in this study are divided into lighting, miscellaneous equipment and people, all heat gains are regarded as being evenly spread over the floor area of the entire building. The average lighting density is 29.9 W/m^2. Allowing for a 25% ballast loss, lighting density totals 37.4 W/m^2. The lighting schedules used are shown in Fig. 4.

Heat gained from miscellaneous equipment for all simulation runs is put at 5 W/m^2. The schedule used for miscellaneous equipment is the same as for people (Fig. 5).

During the daytime, 450 persons work in the building. They all perform normal office tasks and contribute 72 W of sensible heat and 60 W of latent heat per person to the internal heat gains. The personnel occupancy schedule used is shown in Fig. 5.

3. HVAC system

The base-case HVAC system is an all-air constant volume (CAV) reheat system with variable temperature (Fig. 6.). The warmest zone in the building is used as a reference for resetting the central air temperature. Perimeter heating is by hydronic baseboard radiators which are controlled by room temperature thermostats. No economizer control or recovery heat exchanger is installed. The supply airflow is designed to maintain the room temperature at cooling set point.

The main characteristics of the system are summarized as:

- *outdoor airflow*: three different ratios of outdoor airflow to supply airflow are studied: (ventilation air) 100%, 50% and 20%
- *supply airflow*: 4.46 l/s m^2 or 6.4 air changes per hour
- *supply air temperature* (*low limit*): 15 °C
- *minimum room temperature*: (heating set point); 21 °C
- *maximum room temperature*: (cooling set point): 25 °C
- *specific fan power*: 3 kW/(m^3/s), which is obtained by having a fan/drive/motor efficiency of 50% (60% × 90% × 92%), typical for a centrifugal fan equipped with an impeller with forward curved blades,

Table 1
Location and climate design parameters [3]

Heating design dry bulb temperature (°C)	Cooling design dry bulb temperature (°C)	Cooling design wet bulb temperature (°C)	Location latitude (deg)	Average annual dry bulb temperature (°C)	Average annual wet bulb temperature (°C)
−17.8	25.3	17.7	59.7	6.2	4.2

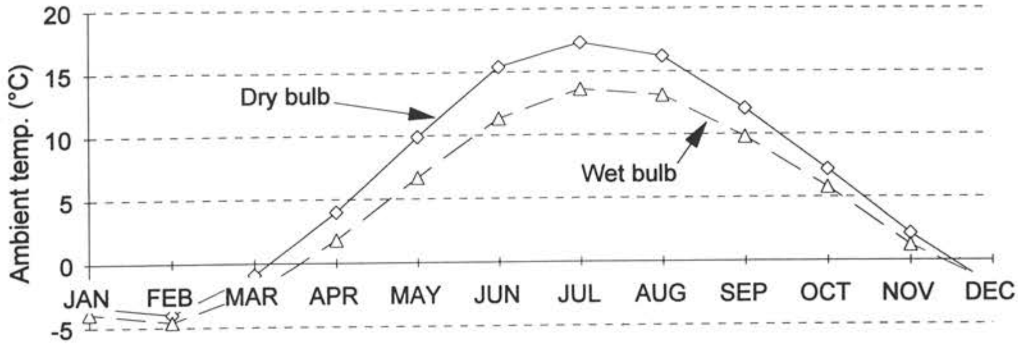

Fig. 1. Average monthly dry bulb and wet bulb ambient air temperatures [3].

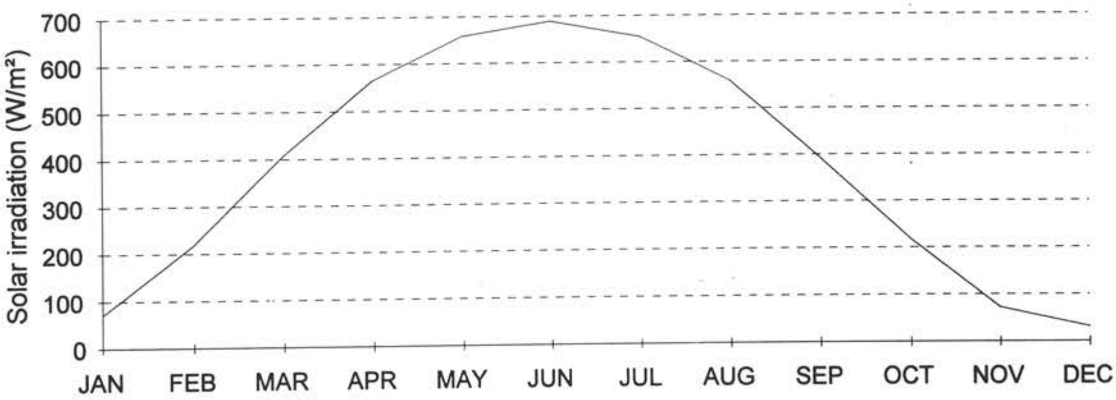

Fig. 2. Design day horizontal solar irradiation [3].

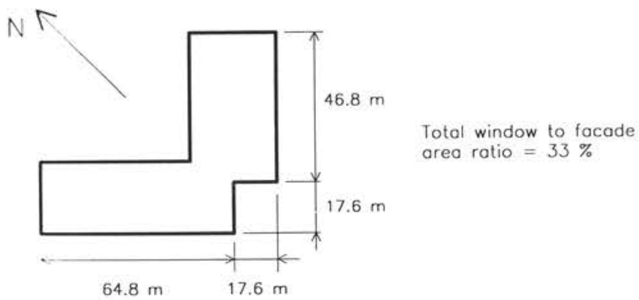

Fig. 3. Base-case building layout and orientation [2].

and a total pressure rise of 1500 Pa, of which 900 Pa is for the supply air fan and 600 Pa for the return air fan.

During periods of occupancy, the supply and return air fans operate continuously to provide a constant air volume rate. When cooling is needed, the supply air temperature is controlled to maintain the zone at the cooling set point. When heating is required, supply air at neutral temperature is provided. Hydronic baseboard radiators in the rooms provide the necessary heating. When neither cooling nor heating is called for, the system provides supply air at neutral temperature and the temperature in the rooms fluctuates between cooling and heating set points (25 °C and 21 °C respectively).

During periods with no occupancy, when cooling is needed, the fans operate to provide a constant air volume rate, and the supply temperature is varied, as above. When heating is required, the fans shut off and the baseboard radiators provide the heating. When

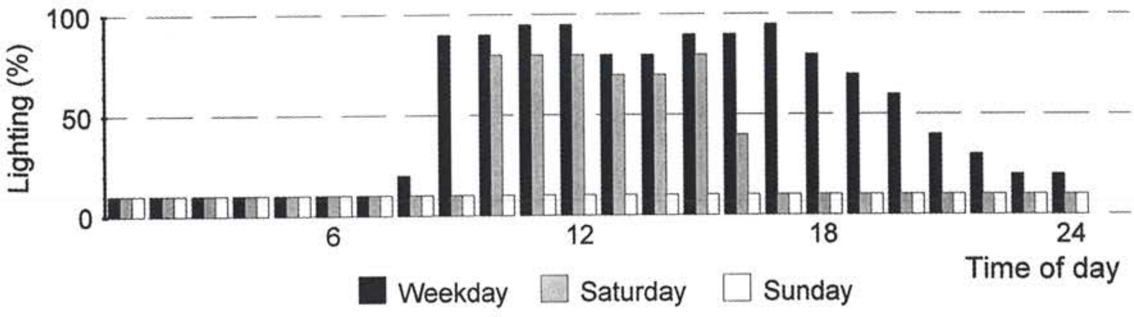

Fig. 4. Lighting schedules used in the base-case building. 100% is equivalent to 37.4 W/m².

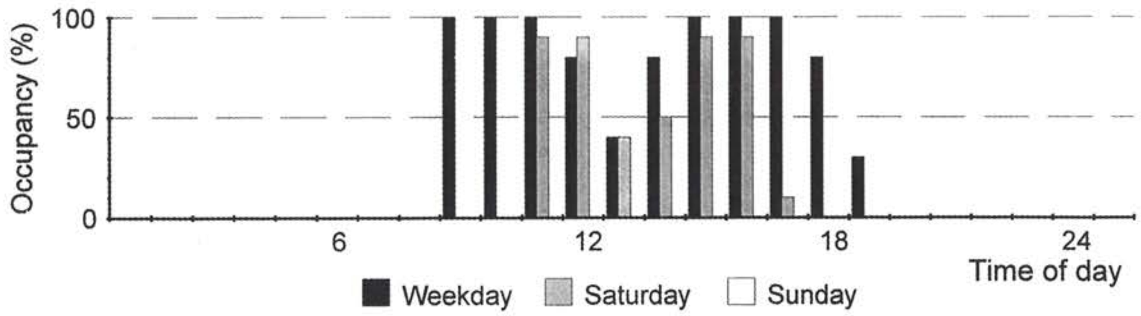

Fig. 5. Personnel occupancy schedule in the base-case building. 100% is equivalent to 450 persons.

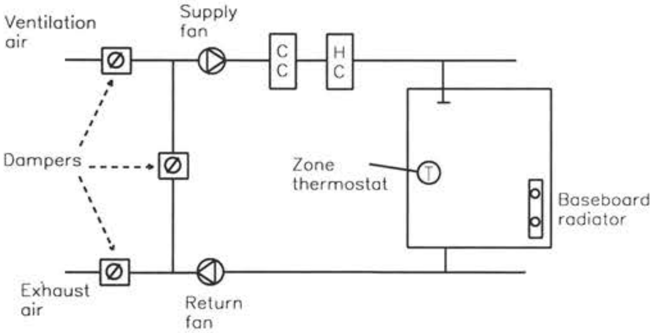

Fig. 6. Schematic design of the base-case building CAV system.

neither cooling nor heating is required, both the fans and the baseboard radiators shut down.

4. Simulated retrofit measures

4.1. Single measures

The simulated measures presented in this article are, as mentioned above, carried out on the internal heat gains, in the form of lighting, on the building envelope and on the HVAC system.

The lighting retrofit measure leads to a reduction in lighting density from 29.9 W/m^2 to 13.9 W/m^2 (with the lighting schedule unaltered). Ballast losses remain at 25% and are added to the lighting density when describing total internal heat generation.

Building envelope retrofit measures are carried out on walls and windows. The effect of decreasing the average U-value for the exterior walls from 1.6 W/m^2 K to 1 W/m^2 K has been examined (in practice, this reduced U-value is achieved by increasing the wall insulation). Also the effect of an alternative window type with a U-value of 1.9 W/m^2 K and shading coefficient of 0.39, has been studied (these new window values correspond to a three-pane window with light-coloured venetian blinds between the two inner panes).

The retrofit measures applied to the HVAC system are simulated in such an order that it is possible to follow the steps as in a retrofitting sequence. As mentioned earlier, the base-case HVAC system consists of a CAV system with three different return-air ratios (0%, 50% and 80%). The first retrofit step is to implement an economizer cycle control, controlled by dry bulb temperatures both in the ambient and return air, respectively. The second step is to remodel into a VAV system using VAV boxes with dampers at the supply air terminals, and using central dampers to ensure constant static pressure control of the old fans equipped with forward-curved blades. The resulting "VAV, old fan" system has a constant supply air temperature. The third step increases the efficiency of the VAV system by replacing the old fans with new ones equipped with backward-curved blades and adjustable speed drives (by frequency inverters). This is defined as a "VAV, new fan" system.

4.2. Combined measures

The first combination of retrofit measures studied involves the reduced lighting measure combined with a series of HVAC measures. The resulting annual energy savings are simulated for four different HVAC systems. The lighting measure has been combined with the different types of HVAC system because the latter's performance with respect to the removal of surplus heat from the building influences the energy savings achieved. Combined retrofit measures have also been examined for walls and windows, again in combination with the four different HVAC systems. The various combined options are summarized in Table 2.

The first retrofit measure with reduced lighting density and with no adjustment of the HVAC system results in excessive flow rates in the CAV systems. The VAV systems, on the other hand, automatically reduce the airflow rates to a lower level, albeit with a somewhat lower fan efficiency in the case of the "VAV, old fan" alternative. In the second retrofit measure with reduced lighting density, the airflow rates are adjusted by changing the fan belt drive. This procedure allows full energy savings to be achieved from the reduced lighting measure, when a CAV system is in use. The same step should also be taken to maximize the benefits if a VAV system with poor fan control ("VAV, old fan") is in use.

Table 2
Combined simulated retrofit measures

HVAC system	Retrofit measure			
CAV return air 80% CAV with economizer VAV, old fan VAV, new fan	Reduced lighting, with no adjustment of the HVAC system	Reduced lighting, with the HVAC system adjusted	Improved windows	Improved walls

5. Results

The diagrams showing the simulation results give the energy needs for the HVAC system divided into heating and cooling needs, as well as electricity requirements. These needs have to be met by the HVAC system in order to maintain the thermal indoor climate of the office building. The electricity requirements are divided into electricity for supply and return air fans, and electricity for chillers. The annual coefficient of performance of the chillers is 3. Consequently, the electricity needs of the chillers become the HVAC cooling requirement divided by 3. Other electricity requirements such as those for lighting and office equipment are examined below, when studying total building energy use.

5.1. Retrofit measures on the HVAC system

In Stockholm, 'free' cooling can, to large extent, be used to cool the building (when the ambient temperature is lower than the required supply air temperature). On the other hand, the need for heating is considerable because the ventilation air has to be heated for most of the year, especially with a HVAC system with 0% return air and no air-to-air heat exchanger between the return and supply air streams ("CAV return air 0%").

As can be seen from Fig. 7, the heating requirement that has to be provided by the HVAC system is considerably greater for most HVAC alternatives than the amount of cooling required by the system. In these cases it might be worthwhile considering retrofit measures designed to reduce the heating requirements.

In most of the HVAC systems studied, the need for mechanical cooling is limited, which is why retrofit measures designed to make the production of cooling more efficient normally give only marginal results. The limited number of systems with large mechanical cooling requirements, especially two of the CAV systems, should preferably be retrofitted into another type of HVAC system.

The electricity requirement for the fans is quite high and, in some of the systems studied, this requirement is the dominant one. Retrofit measures on the fans and air ducts will, consequently, result in considerable savings.

The pattern of energy need is quite clear for the first three base-case CAV systems in Fig. 7. The first system, with 0% return air (equal to 100% outdoor air), shows a considerable heating requirement and only a limited need for machine cooling because of the low ambient temperatures. The third system, with 80% return air, shows the opposite requirements as regards heating and machine cooling because only 20% of the air volume is outdoor air. The fans in the latter system also have a greater electricity requirement because the HVAC system has to operate more during unoccupied periods. As expected, the second system, with 50% return air, shows energy needs which lie in between those of the other two systems.

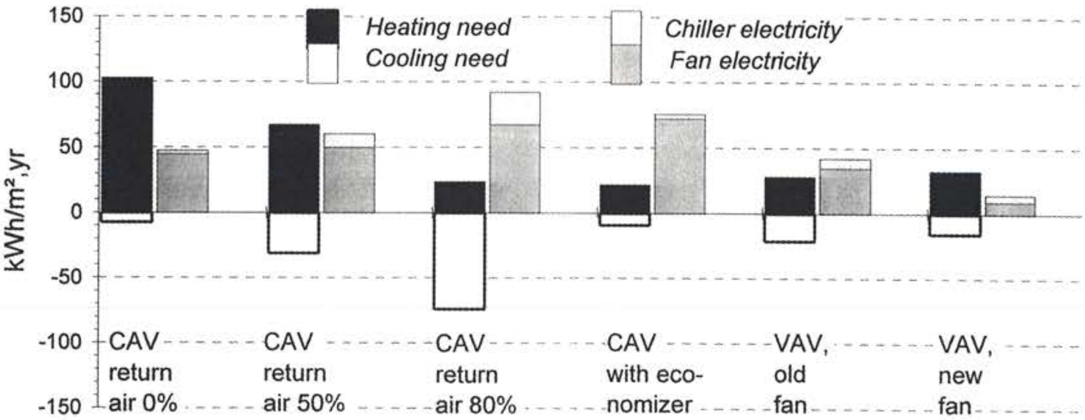

Fig. 7. Energy requirements after the application of retrofit measures to the HVAC system.

The most common HVAC system in old office buildings in Stockholm is probably the first base-case system, "CAV return air 0%", which has a considerable heating requirement. Such systems are normally improved by adding air-to-air heat exchangers: these make use of the warm exhaust air to warm up the cold intake air from outside. The result is approximately the same as for the "CAV with economizer" system. The heating requirement is considerably reduced but, at the same time, total fan electricity needs in the HVAC system show a substantial increase.

By altering the "CAV with economizer" system to one with variable air volume flow controlled by dampers or with frequency inverters, the electricity requirements for the fans are reduced. The first VAV system with a constant supply air temperature and damper control, "VAV, old fan", shows a dramatic reduction in fan electricity requirements. At the same time, however, there is an increased demand for heating because of the higher fan efficiency which reduces the temperature rise of the air when passing the fan (the airflow passing the fan is not heated as much by the fan as is the case where the fan has a lower efficiency). There is also an increased demand for cooling because of the low constant supply air temperature, and also because of lack of economizer advantages in the VAV system during warm summer weather. The second VAV system, with a constant supply air temperature and a new adjustable-speed-controlled fan, "VAV, new fan", shows an even more dramatic reduction in fan electricity requirements. At the same time, there is an increased demand for heating because of increased fan efficiency. Retrofitting into either of these two systems reduces total electricity requirements to a level below that of the initial system.

5.2. Combined retrofit measures

As described earlier, one energy-saving retrofit measure applied to the window, one to the exterior wall and one to the lighting system have been simulated for four different HVAC systems to determine their influence on system operation.

The results arising from retrofit measures applied to the lighting system are given both before and after airflow adjustment. For both VAV systems, this adjustment will take place automatically, albeit with a somewhat lower fan efficiency in the case of the "VAV, old fan" alternative. For the two CAV systems the consequences of altering the lighting system without adjusting the airflows can clearly be seen.

Fig. 8 shows the simulation results for all combinations studied. Fig. 8 shows, for both CAV alternatives studied, that it is absolutely essential to adjust the airflow rates after altering the lighting system, in order to achieve the maximum possible electricity savings within the HVAC system. A correct adjustment leads to a reduction in electricity both for fan operation and for cooling equipment (the design airflow rate is 6.4 air changes per hour before airflow reduction and 4.4 air changes per hour afterwards).

If, however, the base-case building is fitted from the start with a "VAV, new fan" system, the lighting retrofit measure reduces total HVAC electricity needs but significantly increases the heating requirements. The overall result is an increase in total HVAC energy needs (these figures exclude the direct electricity for lighting). Changes in the HVAC system energy requirements due to the improved windows measure as well as the improved exterior walls measure, are small for all four HVAC system alternatives.

5.3. Total building energy use after retrofiting

The total building energy needs comprise the energy requirements of the HVAC system and electricity needs for lighting and office equipment. Service hot water consumption is normally negligible in office buildings, which is the reason why the energy needs for service hot water production are ignored here. Electricity requirements for lighting and office equipment are calculated as shown below (1.25 is the lighting ballast factor which includes ballast losses):

- *electricity requirements for office equipment*: 10 h/day × 250 days/year × 5 W/m^2 = 12.5 kWh/m^2 yr
- *electricity requirements for lighting, base case*: 11 h/day × 250 days/yr × 29.9 W/m^2 × 1.25 = 103 kWh/m^2 yr
- *electricity requirements for lighting, after reduced lighting measure*: 11 h/day × 250 days/yr × 13.9 W/m^2 × 1.25 = 48 kWh/m^2 yr

The total building energy needs consist of the calculated energy requirements shown above, together with

Table 3
Electricity requirements for the HVAC system and for the total building when different retrofit measures were applied

Retrofitting from	HVAC electricity requirements (kWh/m^2 yr)		Total building electricity requirements (kWh/m^2 yr)	
	Before	After	Before	After
"CAV return air 80%" to "VAV, new fan"	92	15	208	130
Base-case lighting to reduced lighting with "CAV return air 80%"	92	30	208	90
Base-case lighting to reduced lighting with "VAV, new fan"	15	6	130	70

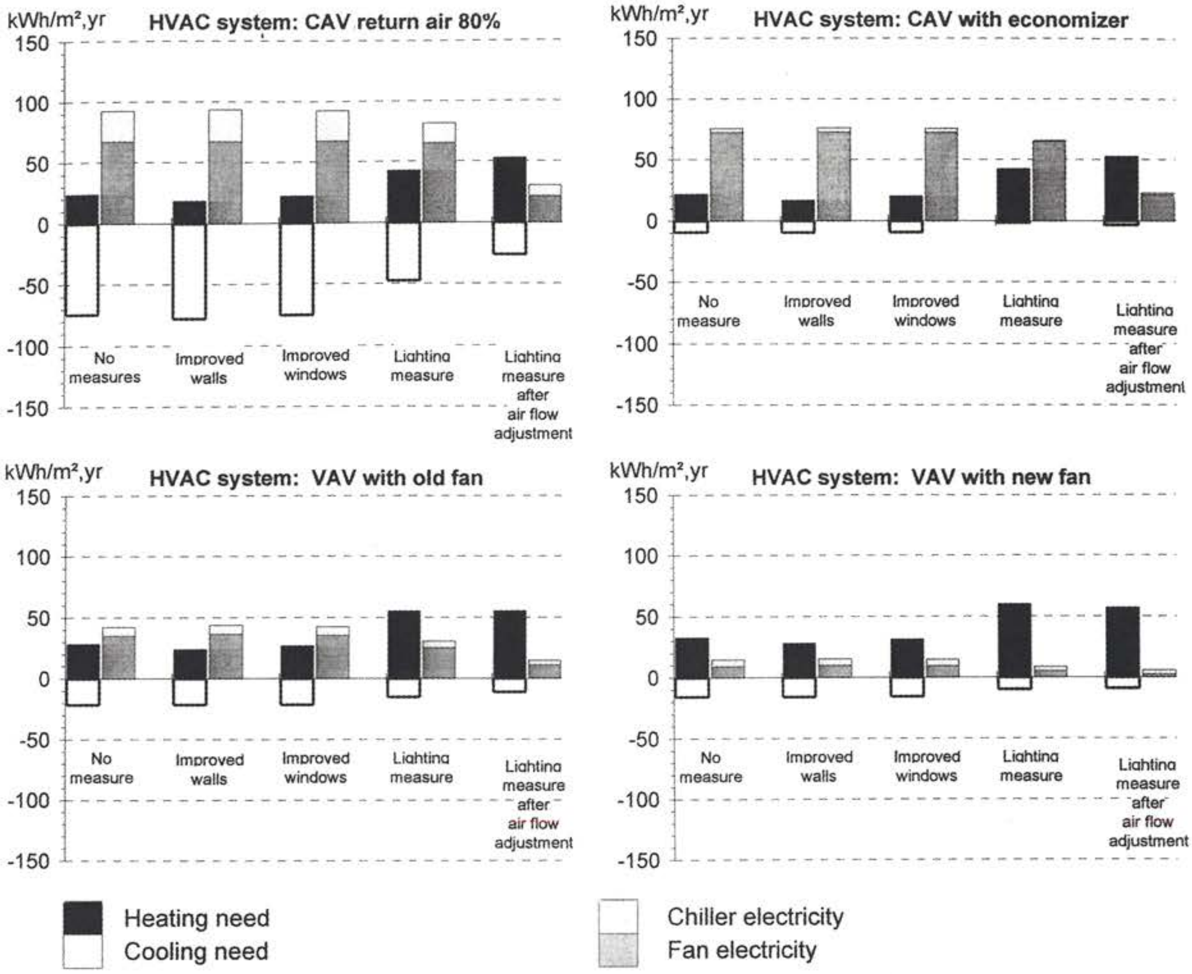

Fig. 8. Energy requirements after combined retrofit measures have been applied to the windows, walls and lighting system of the base-case building.

the energy requirements of the simulated HVAC system. these needs are presented in heating versus electricity diagrams to show the results for the retrofit measures carried out. Table 3 comprises the electricity requirements both for the HVAC system alone and for the total building (HVAC system, lighting and office equipment). The results for the combined measures containing improvements of the building envelope are excluded below, owing to the small changes in energy needs they gave rise to.

Fig. 9 shows the total building energy needs for the building, with retrofit measures applied to both the HVAC system and the lighting system. Between the "CAV return air 80%" and "VAV, new fan" systems, the two other HVAC systems studied are shown. Two lines for lighting retrofit measures have been drawn, starting from the two extreme HVAC systems. These show each HVAC system's influence on the energy savings achieved by the lighting system alterations.

Altering the "CAV return air 80%" system to a "VAV, new fan" system reduces electricity requirements by 78 kWh/m^2 to 130 kWh/m^2, while heating needs increase by 9 kWh/m^2 to 33 kWh/m^2.

When the reduced lighting retrofit measure is applied to the "CAV return air 80%" system, only half of the potential electricity savings are achieved if the airflows in the HVAC system are not rebalanced. After rebalancing, however, the electricity requirements fall by 118 kWh/m^2 to 90 kWh/m^2, while the heating needs increase by 30 kWh/m^2 to 53 kWh/m^2. If the building is equipped instead with the "VAV, new fan" system, the electricity requirements fall immediately by around 60 kWh/m^2 to 70 kWh/m^2 when the lighting density is reduced, while the heating demand increases by 25 kWh/m^2 to 58 kW/m^2. In this case the HVAC system itself adjusts the airflow to the new requirements after the retrofit.

6. Sensitivity analysis — alternative base-case building

The simulations discussed, so far, are based on a base-case building which has an insulation standard

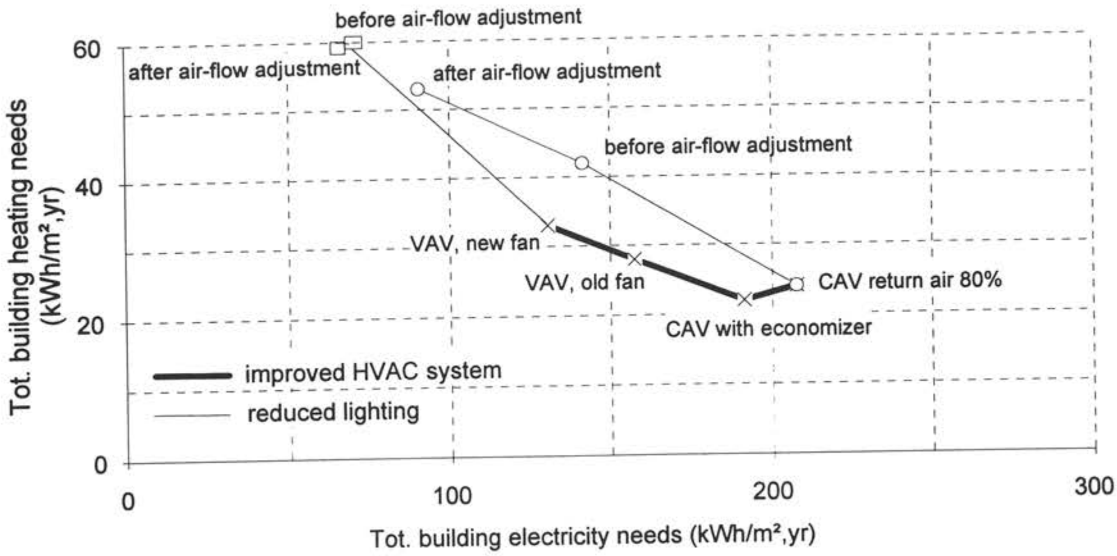

Fig. 9. Total building energy needs.

with poor walls but good windows while, at the same time, it has quite substantial internal heat gains due to the high lighting density. This results in a limited heating demand but large cooling requirements. Even though the main focus of this paper is on this type of office building and energy-saving retrofit measures carried out therein, it can be of interest to look at another type of office building.

What happens if the average overall insulation standard is poorer than is the case for the original base-case building, and the internal heat gains at the same time are considerably lower? One of these 'low internal heat gain offices' is examined below.

6.1. Alternative base-case building

The alternative base-case building studied is similar to the original base-case building apart from the changes examined below.

- *windows*: U-value $=3.1$ W/m² K; shading coefficient $=0.6$ (changed from U-value $=2.1$ W/m² K; shading coefficient $=0.4$)
- *lighting density*: 13.9 W/m² K (compared to 29.9 W/m² K)

The total internal heat gain from lighting and office equipment is now $13.9\times1.25+5=22$ W/m²

- *air infiltration*: 0.48 air changes/hour or 0.36 litres/s m² (floor area) (compared to 0.24 air changes/hour).

6.2. Simulated retrofit measures

The energy-savings retrofit measures simulated for the alternative base-case building are the following:

- *improved wall*: this measure includes exterior wall insulation, giving a reduction in U-value from 1.6 to 1.0 W/m² K and draught-proofing, reducing the air infiltration rate from 0.48 to 0.24 air changes per hour.
- *improved windows*: this measure includes window replacement, reducing the U-value to 2.1 W/m² K and the shading coefficient to 0.4, and also draught-proofing, reducing the air infiltration rate from 0.48 to 0.24 air changes per hour.
- *reduced lighting*: this measure consists of a reduction in lighting density to 8 W/m². The total internal heat gain from lighting and office equipment is then $8\times1.25+5=15$ W/m².
- *improved HVAC system*: the initial HVAC system with CAV and a return air ratio of 0% or 80% ("CAV return air 0%" or "CAV return air 80%") is altered to an efficient VAV system ("VAV, new fan").

As was the case for the original base-case building, the retrofit measures on the building envelope and lighting were first applied to the building, leaving the HVAC system unaltered. The next step was to apply the same retrofit measures in combination with the improved HVAC system. The reduced lighting measure is simulated both before and after airflow adjustment.

6.3. Results of the HVAC retrofit measures applied to the alternative base-case building

All three HVAC systems presented in Fig. 10 have as might be expected, higher heating requirements and lower needs for both cooling and electricity compared with the original base-case building. The increase in heating requirements is the result of a lower internal heat generation combined with increased thermal losses though the building envelope. The reduction in electricity requirements results mainly from the reduced period of fan operation and the lower airflows (al

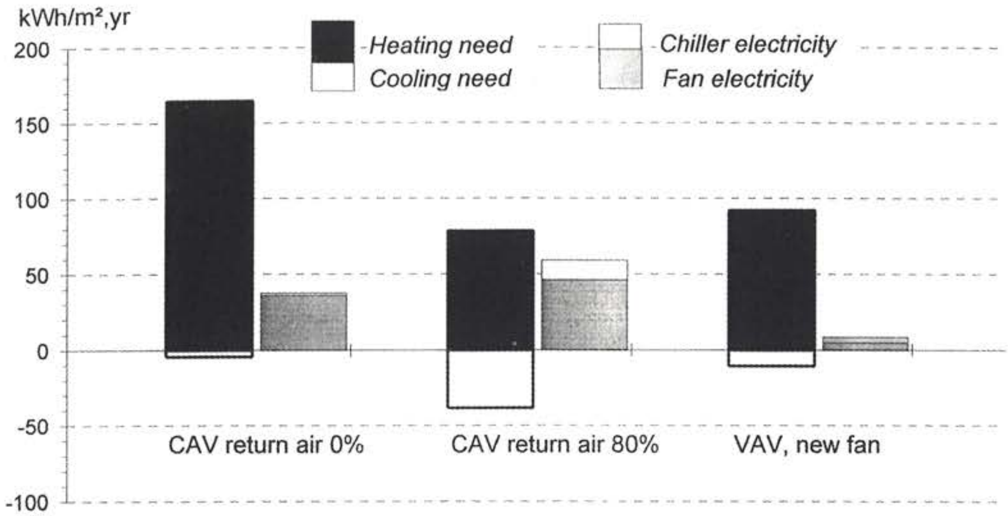

Fig. 10. Energy requirements after retrofit measures have been applied to the HVAC system of the alternative base-case building.

three systems are all-air systems). However, the relative changes in energy requirements when changing from one HVAC system to another are about the same as for the original base-case building.

The "VAV, new fan" system seems to be the most beneficial of the three systems, even though it has somewhat higher heating requirements than the "CAV return air 80% system": electricity requirements are considerably lower than for the other systems.

Fig. 11 shows the simulation results of improving the walls, improving the windows or reducing the lighting density. The results are presented for two of the HVAC systems.

"CAV return air 80%" system: by improving the walls, heating needs are reduced with this system, however, the cooling requirements increase somewhat with a resulting slight increase in electricity need. Improved windows reduce both the thermal heat flow through the building envelope and solar radiation through the windows into the building. This reduces the needs for heating and cooling and, consequently, also for electricity. Reducing the lighting density further reduces the cooling needs and therefore the electricity requirements, but at the expense of a substantial increase in heating requirements. However, a fair judgement of the lighting retrofit measure must also take into account the direct electricity savings of the lighting system itself. This is further discussed in conjunction with Fig. 12.

"VAV, new fan" system: if this system is installed, the electricity requirements are low before any retrofit measures are applied; the energy-saving retrofit measures therefore only marginally influence electricity consumption. The same pattern can be seen for this HVAC system as for the "CAV return air 80%" system. Heating requirements are lowest for the improved windows measure, and greatest for the reduced lighting density measure.

As mentioned above, to judge the lighting retrofit measure more accurately, direct savings by the lighting system must also be taken into account. this is done below, where total building electricity requirements are compared with the heating needs of different HVAC systems and combinations.

6.4. Total energy needs of the alternative base-case building, after retrofitting

Total building energy needs consist of the energy requirements of the HVAC system and electricity requirements for lighting and office equipment. Electricity requirements for lighting and equipment are calculated as:

- *electricity requirements for office equipment*:
  10 h/day $\times$ 250 days/year $\times$ 5 W/m^2 = 12.5 kWh/m^2 yr
- *electricity requirements for lighting before lighting retrofit measure*:
  11 h/day $\times$ 250 days/year $\times$ 13.9 W/m^2 $\times$ 1.25 = 48 kWh/m^2 yr
- *electricity requirements for lighting after lighting retrofit measure*:
  11 h/day $\times$ 250 days/year $\times$ 8 W/m^2 $\times$ 1.25 = 27.5 kWh/m^2 yr.

Total building energy requirements are presented in a heating vs. electricity diagram to show the results of these combinations of retrofit measures.

If starting with the "CAV return air 80%" system and if electricity savings are the priority, the greatest savings would be achieved either by changing to the "VAV, new fan" system or by reducing the lighting density. Both measures, however, increase heating requirements. If, instead, the windows are improved, both heating and electricity requirements fall (even though

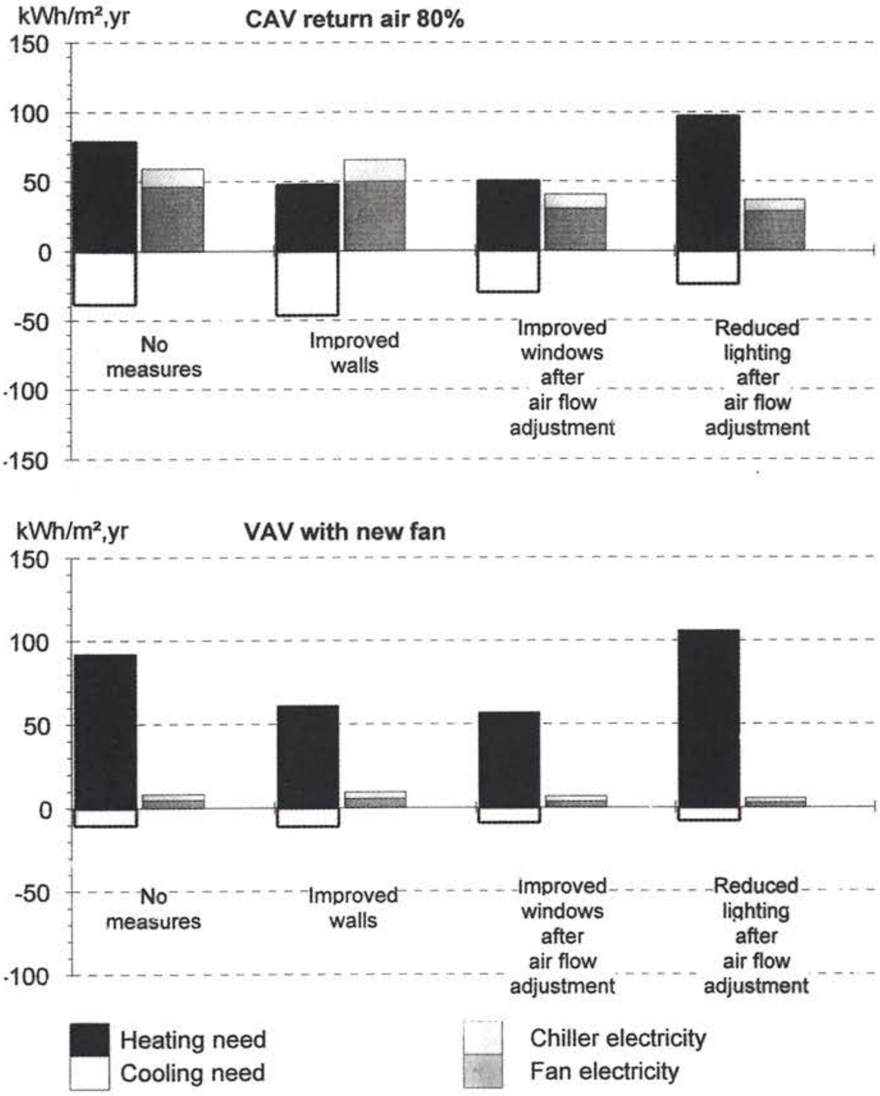

Fig. 11. Energy requirements after improvements to the wall and windows, and after the application of reduced lighting retrofit measures in the alternative base-case building.

the reduction is smaller than for the other two measures). Improving the walls by extra insulation reduces the need for heating, although the electricity requirements increase somewhat.

If applying energy-saving retrofit measures to a building already equipped with a "VAV, new fan" system, the only measure studied which saves electricity is the reduced lighting density measure (although heating requirements are increased). Improving the walls or windows leads to a reduction in heating requirements, with electricity needs remaining approximately the same.

7. Discussion

Simulations of the various energy-saving retrofit measures applied to the HVAC system show that the option that offers the greatest reduction in electricity consumption for fans and chillers is the "VAV, new fan" system.

Measures carried out on the lighting system save electricity both directly in the lighting system and indirectly because of the reduced need for cooling (less electricity for supply and return air fans, and for chillers). The results of applying retrofit measures to the lighting system show the importance of adjusting airflow rates to the new conditions, when this is not done automatically by the existing HVAC system. For HVAC systems with simpler airflow adjustment equipment, an airflow control after a lighting retrofit is also important.

To exemplify the two types of energy saving that can be achieved when altering the lighting system, a comparison is made between direct and indirect savings for the base-case building as follows:

Example: When the base case building is equipped with a "CAV return air 80%" system, every direct kWh/

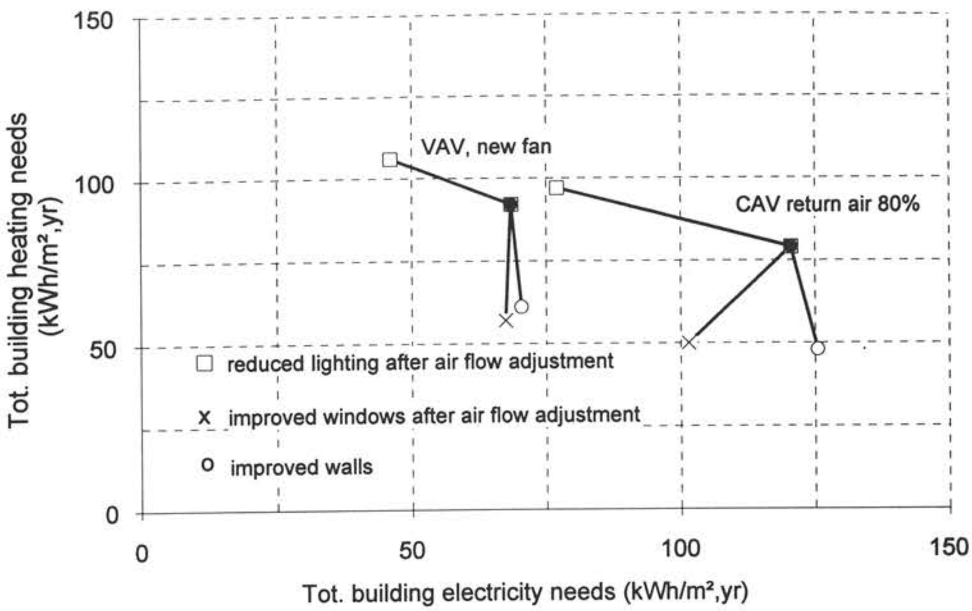

Fig. 12. Total energy requirements for the alternative base-case building.

m^2 yr of electricity saved by the lighting system is accompanied by another 1.15 kWh/m^2 yr of indirect savings of electricity after proper adjustment of the airflows. If the same building is equipped instead with a "VAV, new fan" system, every direct kWh/m^2 yr of electricity saved by the lighting system is accompanied by another 0.45 kWh/m^2 yr of indirect savings of electricity.

All retrofit measures carried out to reduce the internal heat generation in buildings with large annual heat surpluses give rise to the same type of two-fold saving as do the lighting retrofits. However, lighting is usually the dominant internal heat generator.

Possible energy savings in office buildings of this rather common type are dependent mainly on measures applied to the HVAC system or to the equipment responsible for internal heat generation [1]. Improving the building envelope by adding insulation to walls and/ or roof, or by replacing windows, results in only minor changes to building energy requirements (the windows in the original base-case building were, however, of rather good quality).

A sensitivity study has also been carried out to investigate what happens if the retrofit measures are applied instead to a 'poorer' base-case building. Compared to the original base-case building, the alternative base-case building has windows with a higher U-value and a lower shading coefficient: it has higher air infiltration rates, etc., but a considerably lower level of internal heat generation. In this simpler type of office building, measures applied to the building envelope give a more significant reduction in energy needs. Improving the walls by extra insulation reduces the heating requirements, although electricity requirements remain approximately the same. Replacing the windows reduces the needs for both heating and electricity. The electricity reduction results mainly from savings in fan electricity.

The alternative base-case building is quite similar to residential buildings in terms of the retrofit measures needed, since most of the energy requirements are for heating.

However, before any energy-saving retrofit measures are applied to a building, it is important to conduct an energy audit. If this audit is properly carried out it will, for instance, ascertain any inaccuracies in the HVAC control system which give rise to poor performance. It is important to know about such inaccuracies and, when necessary, to make adjustments before deciding on the energy-saving retrofit measures to be applied.

References

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