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EXPERIMENTAL INVESTIGATION OF TIME DEPENDENT LOAD CONFIGURATIONS INSIDE OF A POWER DISTRIBUTION SYSTEM

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Abstract: Within the paper the procedures - for carrying out detailed experimental investigations by the aid of digital Measurement Data Acquisition systems, for evaluating the measuring results as well as for aggregating the load type specific power consumption - are pointed out in general form. The results received concerning the load type specific power consumption are presented and discussed in detail at the example of the 15 MW power distribution system of the University of Stuttgart.
Based on these experimental investigations countermeasures had commercially been installed. As a result of this, 20% of the consumed electrical energy could be saved especially by applying thyristor based speed control to asynchronous motors.

Keywords: Parameter estimation, load modelling, power distribution systems, saving of electric load energy, speed control.

1. INTRODUCTION

The main task of electrical power supply is the continuous adaptation of the power generation to the electric power consumption. The participation of the different types of power plant units feeding in the grid and their corresponding control behaviour are rather well known (DVG, 2000). However, concerning the load behaviour of the different types of consumers, the utilities normally have only slight knowledge (N.N., 1991). They are storing the daily load characteristics of the power distribution systems and do furtheron know the installed load amount of the customers, normally splitted into residential and industrial load.
For more detailed considerations concerning the daily and annual load trends the utilities are interested in the time variable participation of the different consumer types in the total load of the power distribution systems.
But also on the userside, e.g. private users and especially those of large building centres, are interested in possibilities for saving electric energy.
For all these purposes aimed experimental investigations concerning the load behaviour of different kinds of consumers and part systems are required.

2. EXPERIMENTAL INVESTIGATIONS

For evaluating the load type specific power consumption of power distribution systems, extensive experimental investigations have been carried out at the 15 MW power distribution system of the university of Stuttgart (Neifer, 1999). This has been done on behalf of the government in representation of all official building centres within the South-West of Germany. For this purpose the total load characteristic of the university area as well as of the different building complexes and inside of these of specific load part areas have been determined by means of special **M**easurement **D**ata **A**cquisition equipments (MDA-equipments) with high resolution. In addition the power consumption of typical consumer units has been investigated by means of the MDA-equipments.
Concerning the load behaviour of the toal load part system as well as of large building centres the consideration has been carried out over the range of one year, divided into the different seasons and university periods with lectures and without lectures, called "**quarter** (of a year) **measurements**", s. Fig. 2/1.
For considering the load behaviour of individual institutes and common supplies several several "one week measurements" have been performed, too.
The experimental investigations were based on ten MDA-equipments each one consisting of 16 analogous input channels. By means of these equipments there have been recorded on the one hand the active and reactive powers of the different load types - mainly on the 10 kVdistribution level - and on the other hand the line frequency and the corresponding voltage. The latter has

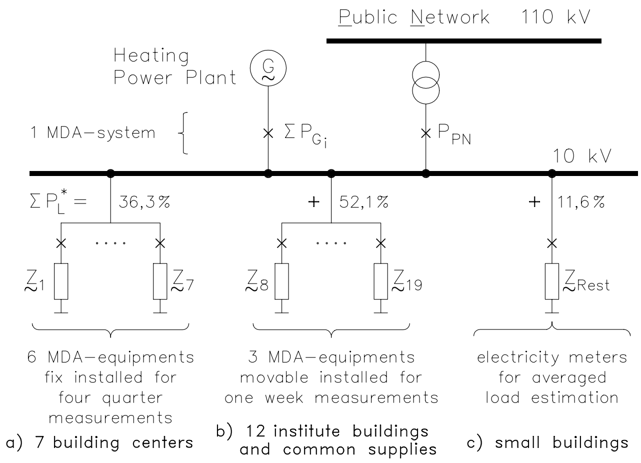

Fig. 2/1: Survey about the power distribution system, investigated by means of ten MDA-equipments

been done for an additional investigation of the voltage dependence of the different load types.

The data logging itself has been carried out with a sampling time of 0.1 sec. This short sampling time has been required for short time recording over a range of $-10 \text{ sec} \leq t - t_0 \leq 20 \text{ sec}$, dynamically triggered by df/dt- and du/dt-criteria at $t = t_0$, and this for the determination of the frequency and voltage dependence of the considered load types.

Besides these dynamically triggered short time recordings, the signal values have been time averaged and stored each time by one minute for the detailed analysis of the load behaviour. This time resolution was required for the evaluation of the power consumption of single consumer units caused by automatically switching on early in the morning and off in the evening or by manual switching off and on at special actuating times.

3. LOAD BEHAVIOUR OF THE 15 MW POWER DISTRIBUTION SYSTEM

3.1 Total Load Characteristic

To the main valuation results concerning the total load there are belonging:

- The load characteristics of the working days are nearly equal. The same belongs to the weekend days.
- Load characteristics of equal day type can be condensed to standard characteristics by ensemble averaging. Therein the deviations between individual and condensed standard load characteristics are smaller than $\sigma = 5\%$, comp. Fig. 3/1.

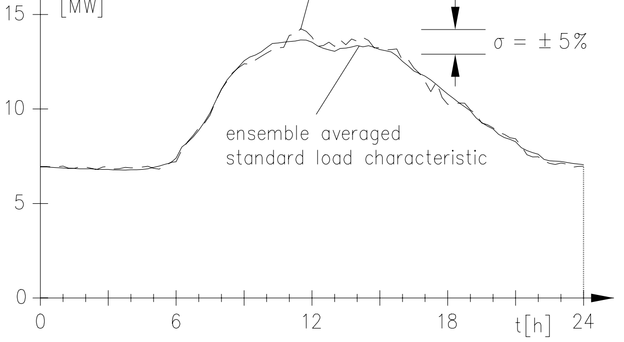

Fig. 3/1: Total load characteristic

- No summer/winter dependence can be recognized at the standard characteristics neither for the working days nor for the weekend days, s. Fig. 3/2. This is mainly caused by the separate heating power supply of all buildings inside of the university area, caused by co-generation within the belonging heating power station.
- The total load of the university area differs for the quarter measurements "within lecture times" and "outside lecture times" only by 1 MW ≙ 7%, and this also only during the working days, s. Fig. 3/2a.

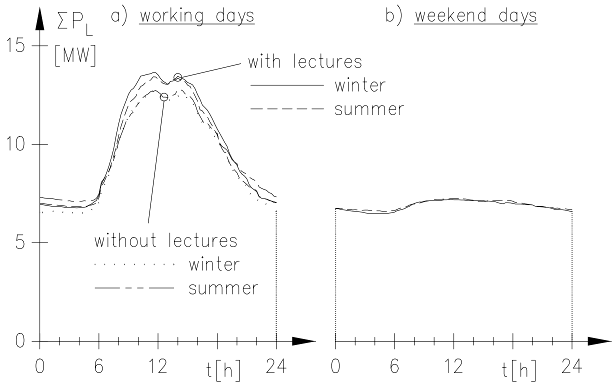

Fig. 3/2: Comparison of season- and lecture-dependent standard load characteristics

3.2 Load Characteristics of Building Complexes and Common Supply Equipments

For the following investigations only the quarter measurements "summer with lectures" will be considered. This is sufficient because of the small deviations of the standard load charcteristics within the four quarter measurements. Fig. 3/3 shows besides the total load characteristic with the peak load of $\sum P_L^{*}$ [1) = 100% also the distribution on the different building centres, the individual buildings and the common supply equipments.

Therein the summed up load percentages of the different building types and supply equipments are listed up, too.

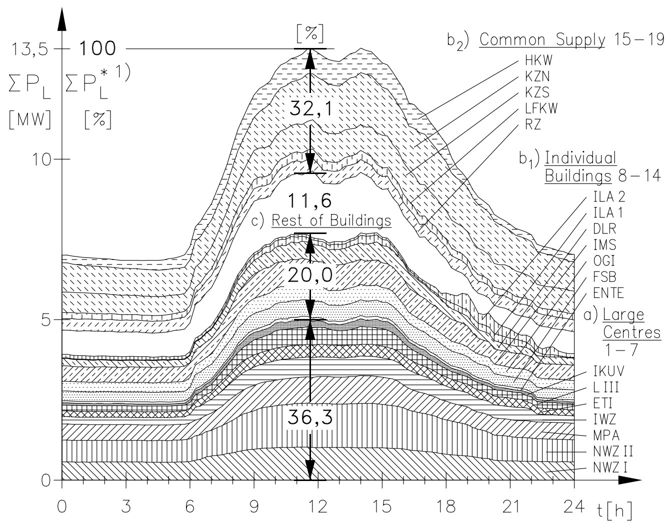

Fig. 3/3: Load characteristics of all buildings and common supply equipments

a) four seasons load recordings

b) one week load recordings

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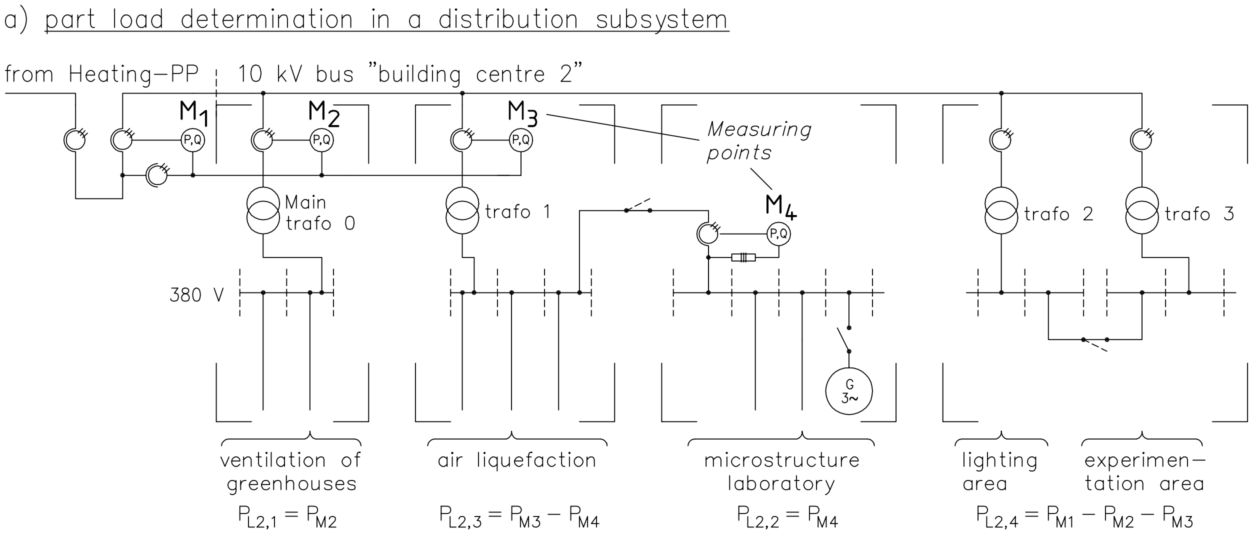
1) $X^{*} = X/X_{100}$



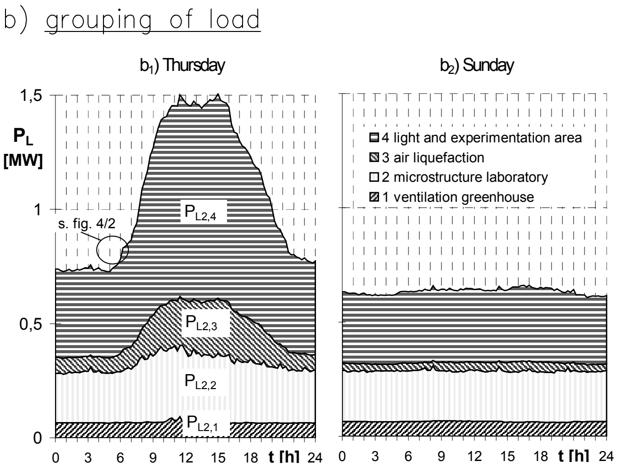


Fig. 4/1: Power consumption of load part areas, shown for building centre 2 "physics"

4. PART LOAD MEASUREMENTS

For being able to analyse the load behaviour in more detail within the large building centres also special load portions have been investigated.

In Fig. 4/1a the method for determining the different load portions P_{Lij} by the measurable part loads $P_{M\mu}$ is explained. Fig. 4/1b shows for example the resulting subdivision of the load behaviour inside of the building centre 2 "physics".

Besides the different load portions also the load consumption of individual consumer groups could be determined, so for instance:

- by detailed evaluation of step-shaped changings in the load characteristics caused by time controlled switching on or off of consumer groups, illustrated in Fig. 4/1b and 4/2a for the case of automatic switching on ventilators as well as lightings at about 6 a.m.
- or by manual switching off or on single consumer units, as shown in Fig. 4/2b.

Such detailed investigations have been possible on the one hand due to the high resolution of the applied MDA-equipments. On the other hand the accuracy concerning the load evaluation could be improved by ensemble averaging, after the corresponding consumer groups having switched off or on several times under same conditions.

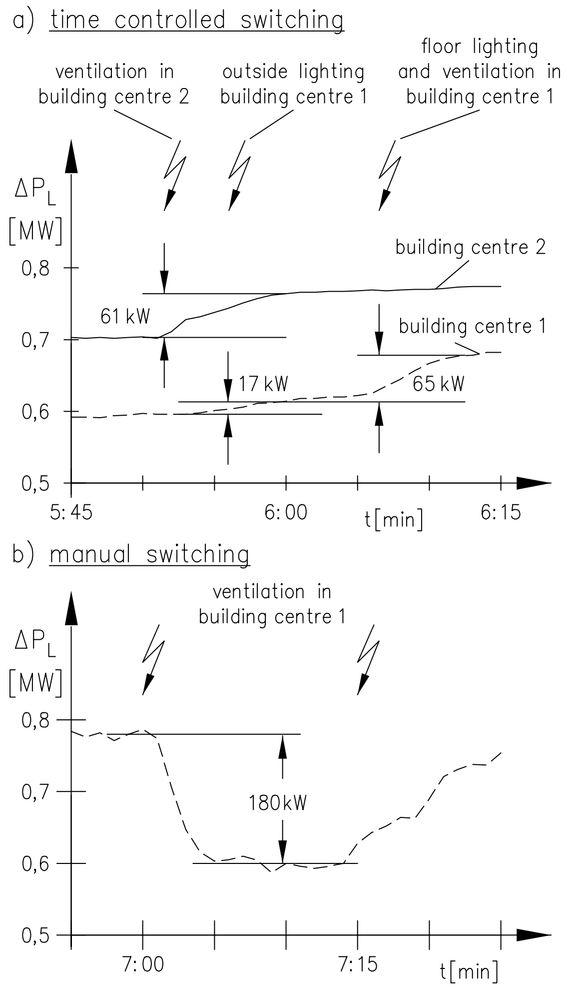


Fig. 4/2: Measured load consumption of individual consumer units

5. CONSUMER TYPE SPECIFIC LOAD CHARACTERISTICS

Basing on the evaluation results described above, the consumer type specific load portions being active within the considered power distribution system could be determined, s. Fig. 5/1. Therein load portions belonging to the common supply equipments within the university area, like the auxiliaries inside of the heating power station as

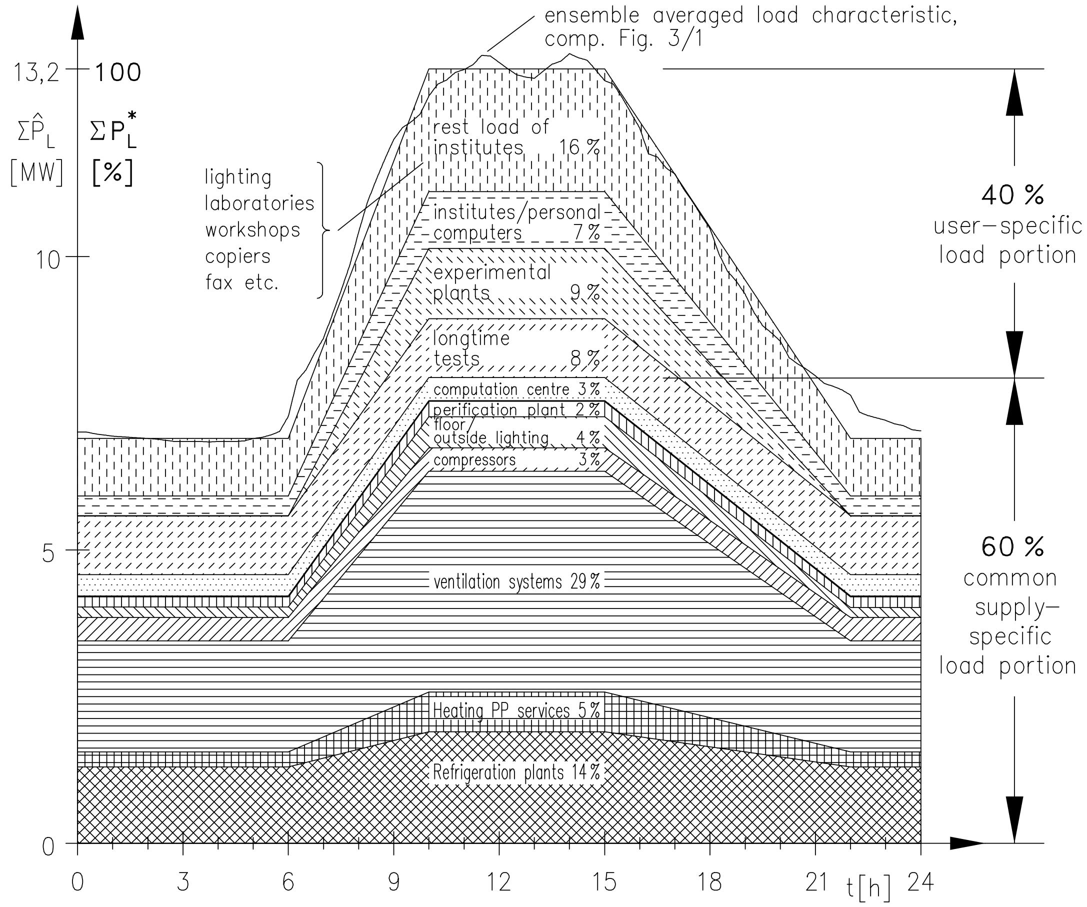


Fig. 5/1: Consumer type specific load characteristics
=> summed up consideration

well as the refrigeration plants, could be determined directly by the measurements.

In this context it has to be marked that the load portion of the refrigeration plants is higher in summer caused by the increasing cooling demand, whereas the load portion of the auxiliaries of the heating power supply is higher in winter due to the increasing heating demand. However as to be seen by Fig. 5/2 the summed up load portions of the auxiliaries are nearly equal in summer and winter.

The determination of the other consumer type specific load portions has by others been done:

- by the measured load characteristics of the considered building complexes,
- by the corresponding characteristics of specific load areas inside of the buildings,
- by the evaluated automatically switching on and off of consumer units,

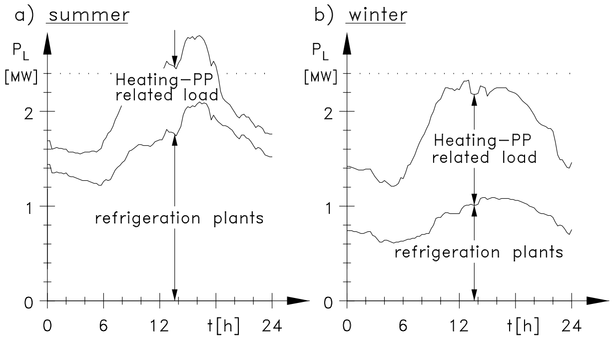


Fig. 5/2: Season-dependent load characteristics of common auxiliary supply equipments

- by the aimed switching of load units, like lighting, fan units, compressors and lifts, as well as
- by the measured power consumption of typical personal computers and workstations aggregated by the number of corresponding computers running inside of the university area, based on estimations of the university computation centre.

Furtheron there has been regarded the special knowledge of the technical staff, responsible for the technique inside of the building complexes as well as for the common supply equipments.

As to be seen by Fig. 5/1 the load aggregation has been done for the nearly constant load behaviour within the peak-load period from 10 ÷ 15 h as well as for the low-load period from 22 ÷ 6 h. For the meantimes a linear load increase in the morning and corresponding decrease in the evening has been assumed.

To the main results of this consumer type specific load aggregation there do belong:

- The summed up load portion for common supply inside of the university area runs up to **60%** of the total load (abbreviated t.l.); therein 48% t.l. are needed for ventilation, cold water refrigeration and heating pump services.
- Within the remaining user specific load portion of **40%** t.l. the main part with 24% t.l. is needed for the power demand of experimental plants and longtime tests particularly in the field of mechanical engineering as well as for personal computers and workstations.
- The remaining load portion of the individual institutes is not greater than 16% t.l.

Regarding these results it is already reasonable that even in a university area - with only a small portion of private load within student houses and the few staff flats - the low load level during night and weekend is generally greater than **50%** of the peak load during working days.

6. POSSIBILITIES FOR REDUCING POWER CONSUMPTION

As the load portion for ventilation is with 29% t.l. the largest one by far, additional analyses have been carried out concerning the origins of such high power demand and based on this for deriving possible countermeasures.

In the following the basis ventilation of the building centre 2 "physics" has been considered more detailly, having a power demand of 35 kW $\hat{=}$ 1% of the summed up ventilation load inside of the university area.
Therein basis ventilation systems generally have the task to supply office rooms, workshops, laboratories and floors with inlet air, i.e. a mixture of fresh and return air flow, heated up or cooled down to room temperature.
The ventilation system considered consists of two fans being equal in construction and throttable continuously by variable blad positioning y and operatable by low speed n_0 = 980 min^{-1} and high speed n_1 = 1970 min^{-1}.

The corresponding load behaviour ΣP_L, measured in dependence of the air volume flow $\dot{V}$ for different blad positions y and recorded by one of the MDA-equipments, is presented in Fig. 6/1a. As to be seen by the continuous lined curves three kinds of load behaviours were determined by measurements

- on the one hand for the operation of both fans at low speed n_0, leading to the load behaviour

  o——o——o $\quad P_{L1} + P_{L2} = f_1(y, n_0) + f_2(y, n_0)$
- and on the other hand for the operation of only fan 2
  - - at low speed n_0 leading to the load behaviour

    x——x——x $\quad P_{L2} = f_2(y, n_0)$
  - - as well as at high speed n_1 leading to the load behaviour

    □——□——□ $\quad P_{L2} = f_2(y, n_1)$.

Additionally there is shown in Fig. 6/1b by dashed lined curves the corresponding computed speed dependent load behaviour for non-throtted blad position y_{100}, leading to the load behaviour

\- - - - - - $\quad P_{L1} + P_{L2} = f_1(y_{100}, n) + f_2(y_{100}, n)$

as well as to the load behaviour

— — — $\quad P_{L2} = f_2(y_{100}, n)$.

As to be seen in both cases the computed load curves - increasing by third potence of the air flow $\dot{V}$ (Recknagel *et.al.*, 2001 - meet the measured curves at the blad position y_{100}.
The majority of ventilation systems has been driven since buildings' errection with constant air flows. In the considered case this corresponds to the operating point "0" with

$$\dot{V}(0) = 122 \cdot 10^3 \text{ m}^3/\text{h} \;\hat{=}\; 100\%,$$
$$\sum P_L = 33{,}5 \text{ kW} \;\hat{=}\; 100\% \text{ and}$$
$$y(0) = 81\%.$$

However such a high air flow is not necessary round the clock, but only during the working time for the well-behaviour of the students and the staff, being active inside of the buildings. Within the long night and weekend periods quite smaller air rates are sufficient. Reducing the air flow during these periods "outside working time" to operating point I with $\dot{V}$ = 75% there can be saved – as to be seen by Fig. 6/1 – $\sum \Delta P_L^*$ = 21% load in the case of air flow throttling and even $\sum \Delta P_L^*$ = 64% in the case of continuous speed reduction, see operating point III (each time refered to the basic operating point „0").

In the majority of applications a further reduction of the air flow e.g. to $\dot{V}^*$ = 50% will be possible. Doing this in the case of throttling $\sum \Delta P_L^*$ = 61% load can be saved, see operating point II, or even 90% in the case of continuous speed reduction, see operating point IV.
Therein corresponding to operating points I and II electric load energy and costs of 21 or 61% respectively can at once be saved only by changing the operation mode, i.e. without improved control equipment.
In addition to this load energy can be saved of about 10% by shortening the duration with full flow operation $\dot{V}_n^*$ = 100% in the early morning as well as in the evening, i.e. before and after the actual working time.

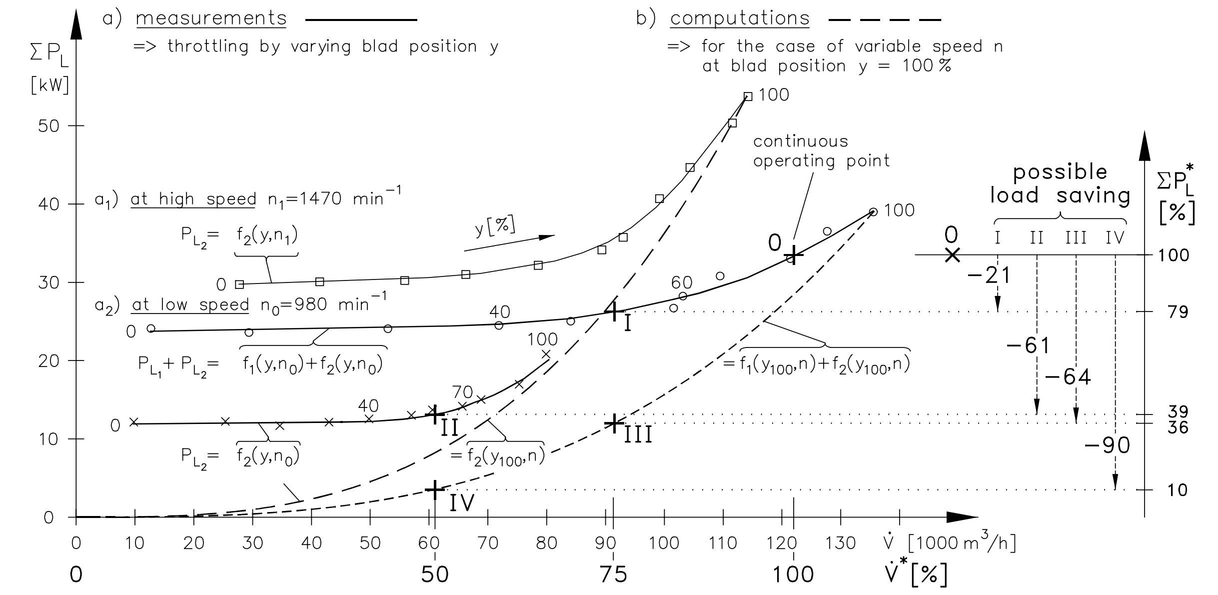


Fig. 6/1: Air flow dependent load characteristics of ventilators for different operating conditions

By such systematical considerations exemplarily carried out it can be seen that in the majority of "older" building centres doing not contain modern ventilation control equipment, essential percentages of load and due to this of energy costs can be economized.
These results received for the considered university area with a load portion for ventilation of 29% t.l. tend to be also valid for the majority of corresponding older office buildings in the field of public and commercial administration as well as in industry.

7. SUMMARY

For analysing the time-dependent load behaviour of electric load part systems the 15 MW power distribution system of the University of Stuttgart had been investigated in detail by means of ten Measuring Data Acquisition equipments within a one year's duration.
Based on these comprehensive experimental investigations the consumer type specific load portions contributing to the total load characteristic have been determined.

By this load aggregation it could be proved, that the summed up user-specific load portion runs up to only 40% of the total load and this also during the working time. From the common supply-specific load portion of 60% of the total load 4/5 are needed for air ventilation, water refrigeration and heating pump services. By means of additional investigations the reasons for the high load level of the installed ventilation systems during day and night time could be determined, combined with possible countermeasures for corresponding load reduction.
To the main ones there belongs the fact, that mass flows should not be decreased by passive actuators[2)], i.e. by varying blade or valve positions, but – for avoiding throttling losses – as far as possible by active actuators, i.e. by speed regulation of pumps or compressors. In our days such regulation can easily be applied by thyristor based speed control of asynchronous motors, a measure which has to be reinstalled in older building centres.

An other countermeasure consists in the adaptation of the common consumers as far as possible to the actual users' demand, i.e. the duration and magnitude of cooling and ventilation of lecture halls, laboratories etc. as well as of the operation of other building aggregates.

The results – exemplarily received by this systematical investigation – are largely valid too, for the majority of corresponding older office buildings in the field of public and commercial administration as well as in industry.

Appendix A1 gives an example for commercially sparing electric energy consumption.

8. REFERENCES

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[2)] in the sense of mass transport

APPENDIX A1

Based on the good results received by the experimental investigation carried out some years ago (Neifer, 1999), the department for technical services of the University of Stuttgart and the commercial engineering office SULZER-INFRA concluded the following energy saving contract:
The engineering office installs the required energy saving measures and the university repays for seven years the money having been saved by reduced energy consumption.
To the measures for saving electrical energy there have belonged among others speed regulation of asynchronous motors or in the case of over-dimension new motors/working machines with reduced nominal power.

Fig. A1 shows the aimed reduction of electric load within two typical building centres for electrical and mechanical engineering. Starting from the reference years 1995 and 1996, the electrical energy measures have been installed 1997 in the ETI (Elektrotechnische Institute, area 1) and 1997/98 in the IWZ (Ingenieurwissenschaftliches Zentrum). As to be seen by Fig. A1 in the average

$$\frac{0{,}64+0{,}54}{3{,}4+2{,}5} = \frac{1{,}18\,\text{GWh/a}}{5{,}9\ \text{GWh/a}} \;\hat{=}\; 20\%$$

on electrical energy consumption could be saved in the years 1999 and 2000. Based on a price of e.g. 100 €/MWh this corresponds to 118.000 €/a for the two building centres considered.

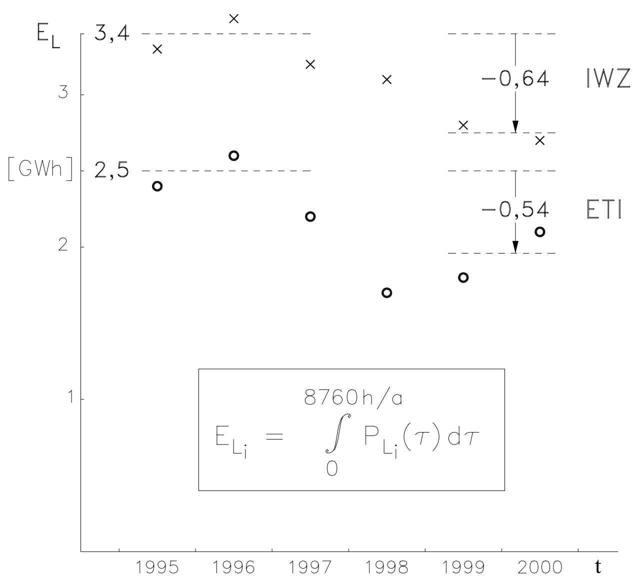

Fig. A1: Reduced electrical energy consumption of the building centres "ETI" (1) and "IWZ"