TECHNICAL NOTE

Summary The HVAC systems of large buildings are significant energy consumers. A great number of interactions have been making it more difficult to find criteria for the selection of structural, mechanical and electrical systems and the minimisation of the particular energy users consumption. The development of a method that would enable the analysis of energy requirements for the alternative types of HVAC systems, and would also give to the designer the possibility of selecting a system which minimises the operating costs and capital expense, would help. This paper presents the energy analysis and its application in the selection of the HVAC systems in the preliminary design phase of a new hospital complex in Zagreb, Yugoslavia.

The analysis of the integrated HVAC system

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1 Description of the method

1.1 The analysis program

The integrated HVAC system shown in Fig. 1 consists of the users and suppliers of energy. The analysis program (Fig. 2) enables records to be kept of energy and media consumption which are the main parameters for the selection of a system. Computer programs have been developed that will simulate the operation of buildings and their HVAC and energy systems, and will calculate monthly and annual energy and media requirements. The analysis program is based on the modular concept with the elements as basic units. The sub-systems are obtained by mutual connection of the elements while the integrated HVAC system is obtained by mutual connection of the sub-systems.

1.2 The input values

The input values of the system are weather data and the characteristics of the building. The weather data are entered into the program in an hour-by-hour format, while the building characteristics data includes orientation, wall area, roof area and glass area as well as the building operational characteristics (i.e. hours of occupancy plus equipment and process operation) it also includes temperature and humidity setpoints in the building zones.

1.3 The building load

The building load is calculated on the basis of the input values. The total building load is the sum of the building zone loads and is based on the instantaneous values of temperature, heat transfer and internal loads.

The computer program for the calculation of the building load is based on methods presented in Ref. (7).

1.4 Users of energy

The system simulation gives the amount of energy and media that must be supplied to the users (primary heating and cooling processes and equipment) in order to meet the imposed building load. Therefore the program uses a mathematical model which includes the elements, sub-systems and processes which form the mathematical model of the system. The system energy and media consumption required to overcome the building load is calculated hour by hour (8670 hours) over a typical year. It is assumed that system operation is constant within each hourly interval.

1.5 Suppliers of energy

If the system is supplied by public utilities, the simulation gives the monthly and annual requirements of energy and media for each alternative system. If the system is supplied partly by public utilities and partly by on-site suppliers, a mathematical model of each site supplier must be made. The suppliers (boiler plant, water chiller plant, etc.) are modelled in the same way as those mentioned above, using the elements (steam boilers, water chillers, cooling towers, etc.) as basic units.

Mathematical models are based on methods presented in Ref. (8).

1.6 Output values

The output values of the energy analysis program give daily, monthly and annual energy and media requirements of the integrated HVAC system. They provide enough information for system selection and economic analysis (i.e. operating costs, capital expense).

The program is illustrated in the flowchart in Fig. 3 and Table 1.

2 Application of the method

The method described above was applied to the study of energy requirements in the pre-design of a new hospital

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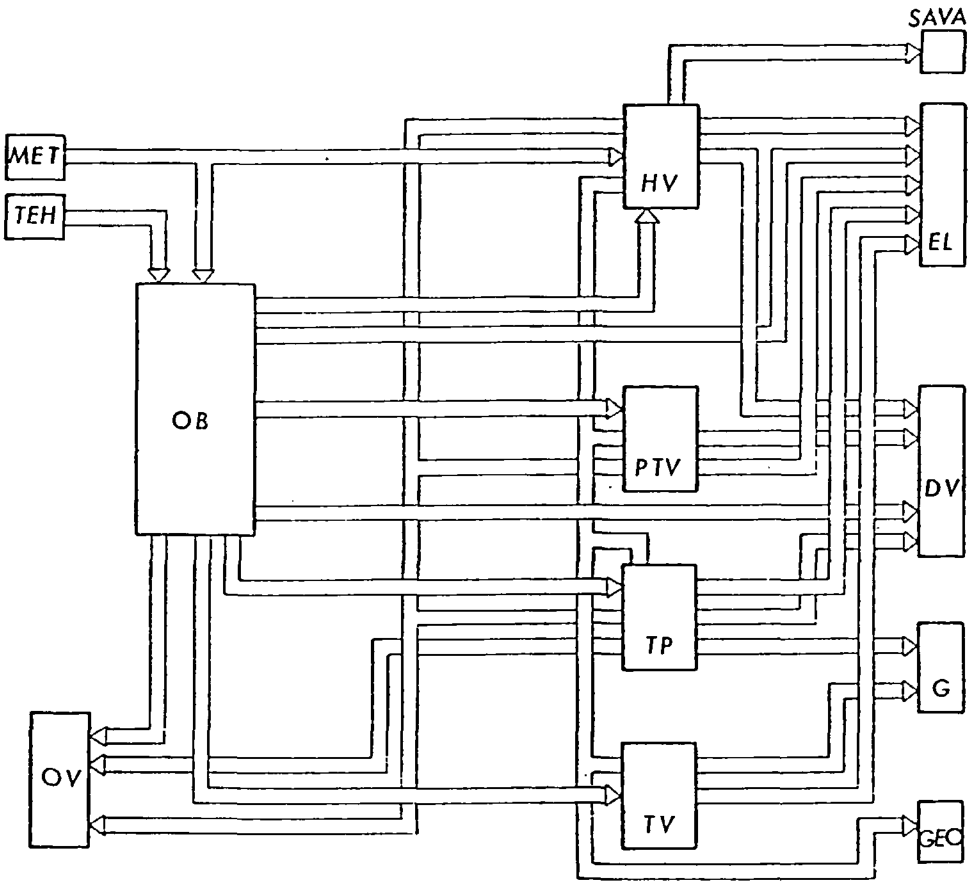

Fig. 1. Schematic of integrated HVAC system:

	Input values:		*Output values:*
MET	*weather data*	*SAVA*	*river water*
TEH	*operating characteristic*	*GEO*	*geothermal water*
OB	*object characteristic*	*EL*	*electric energy*
	Suppliers:	*DV*	*fresh and make-up water*
HV	*chilled water*	*G*	*fuel*
TV	*hot water*	*OV*	*waste water*
TP	*steam*		
PTV	*sanitary water*		

complex with a capacity of 1000 beds and a total area of 130000 m². The aim of the study was to find the energy and media consumption of various suppliers' alternatives. The output data made a basis for planning the public and on-site sources and estimation of the operating costs and capital expense as well as the basis for the system design approach.

The input data were obtained from the Yugoslav National Weather Service, urban conditions and medical program. The hospital complex is planned to be built by a river in a non-urban area. The number of objects, their shape, position, wall area, roof area, glass area, number of zones with a specified number of people and process loads and physical characteristics were defined. The microclimatic conditions in the zones were defined by the temperature set point together with the humidity percentages in winter and summer periods. A typical year for the hospital complex location was selected from the hourly observation of weather data (temperature, humidity, cloud cover and solar radiation) for a twenty year period.

The building load was calculated over 8670 hours of a typical year. The peak values were also calculated for the summer and winter project parameters. The building load values were used as the input values for the simulations of the HVAC systems. Mathematical models of the equipment and processes were made for dual duct, induction, ventilation, fan-coil and heat recovery systems.

The system of the suppliers was selected from a few alternatives based on the following assumptions:

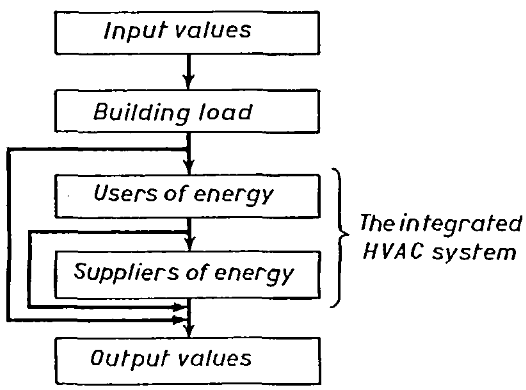

Fig. 2. Flow diagram of energy analysis.

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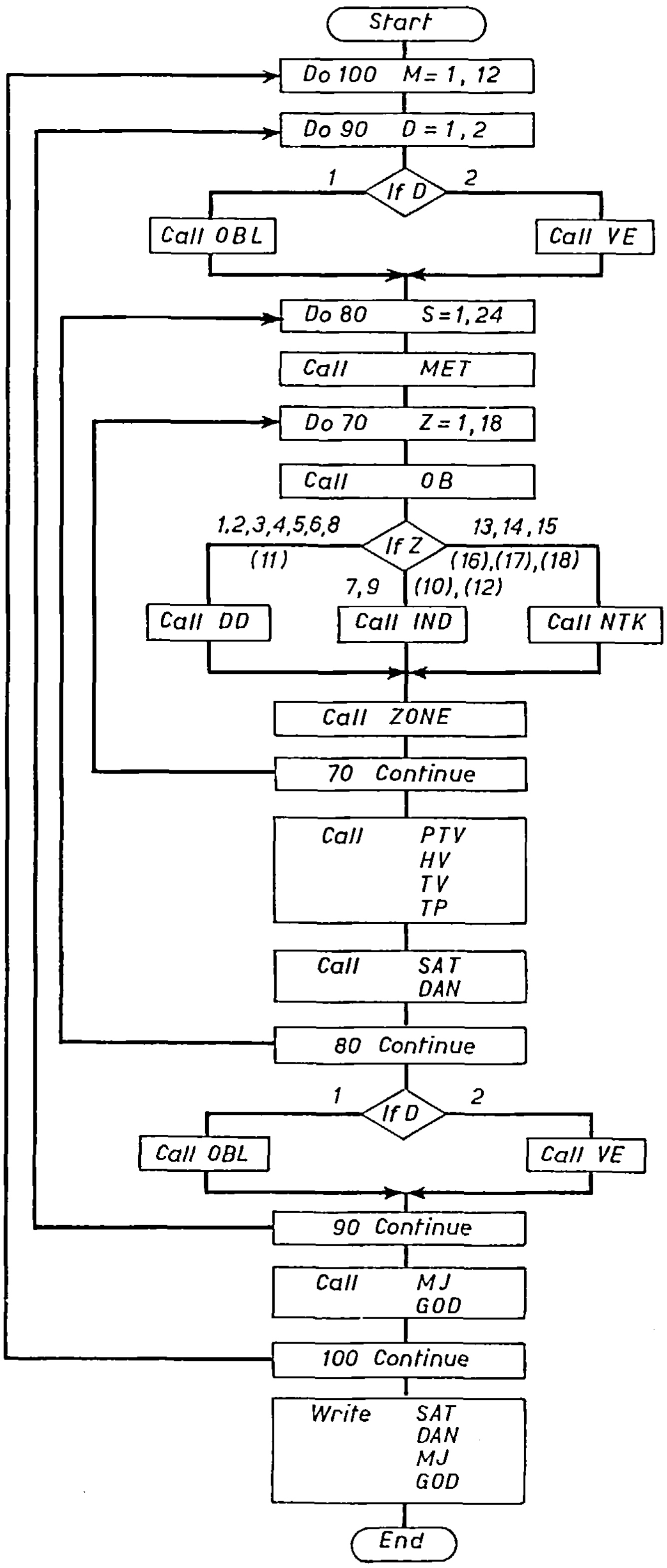

Fig. 3. Integrated HVAC system flow chart. (For subroutines and nomenclature see Table 1.)

(1) electrical energy supplied by a public utility.

(2) fuel (gas) supplied by public utility.

(3) geothermal water supplied by the on-site geothermal source with the capacity of 100 m^3/h and temperature of 57°C. Geothermal water was foreseen for sanitary hot water.

2.1 Hot water and steam supplier

The alternative of on-site hot water and steam boiler plant was selected.

2.2 Chilled water supplier

The following alternatives were observed:

(1) Water chiller plant with centrifugal compressors and cooling towers.

(2) Water chiller plant with centrifugal compressors using the river water for condensation.

(3) Water chiller plant having double condensers centrifugal chillers and condensing temperature of 43°C.

(4) Water chiller plant having double condenser and evaporator centrifugal chillers and possibility to operate as a heat pump system.

(5) Water chiller plant having absorption steam-fired units.

The equipment selection for the integrated HVAC system was made on the basis of the peak values.

3 Results

The alternative which assumes the use of the heat of condensation (2.2.3) demands a large accumulation for the spring and autumn periods. The alternative with water chillers having the possibility of operating as a heat pump was not justified because of the high capital costs and the short period of use during the year. Very low river water temperature in December, January and February cause the low efficiency of the heat pump just at the time when it is needed . Instead, the alternative which assumes the use of the river water for condensation was suggested.

The annual requirements for the observed alternatives are given in Table 2 while the integrated HVAC system requirements for heating (Q_G), cooling (Q_H), steam (P_K), fresh and make-up water (DV), el. energy for the water chillers (EL-RS) and gas (G) are given in Fig. 4. The cross-hatched areas in the diagrams refer to the alternative with heat-recovery system.

The diagram in Fig. 5 illustrates the amount of the condenser heat (Q_K) available during a year in the comparison with heat requirements (Q_G). The cross-hatched area shows the amount of the condenser heat which can be used while Q_{DT} is the heat demanded from the heat pumps.

4 Conclusion

The study illustrates how the method of analysis of the integrated HVAC system can be applied to the pre-design phase of a complex facility. It is shown that the analysis program is a valuable tool that can be used:

(1) For observation of facility requirements,

(2) For the selection of alternatives.

Quantitative data of the energy and media consumption of the integrated HVAC system together with an analysis of both capital and operating costs will lead to a rational decision.

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Table 1 Specification of the sub-routines (see Fig. 3)

Sub-routine name	Function	Sub-routine arguments Input	Output
MET	Select the weather data	M,D,S	TO,FIO,TVT,TS, FVE,FOB
OB	Calculates object Load by zones	M,D,S,Z	QP,GZ
DD	Calculates the energy and media consumption for Dual Duct systems	TO,FIO,QP,GZ	QH,QT,PVL,QB, ELDD
IND	Calculates the energy and media consumption for Induction systems	TO,FIO,QP,GZ	QH,QT,PVL,QBH, QBT,ELIND
NTK	Calculates the energy and media consumption for Ventilation and Fan-coil systems	TO,FIO,QP,GZ	QH,QT,PVL,QB, ELNTK
TV	Calculates the hot water consumption	QTZ,Q	GTV
PTV	Calculates the sanitary water consumption	S	DVPTV,PPTV
HV	Calculates the energy and media consumption for the chilled water suppliers	JOB,QHZ,TVT,TS	EL,DVHV,QK,RV
DT	Calculates the energy and media consumption for the heat pumps	QX,TS,RV	EL,DVDT,QTP,QZ
TP	Calculates steam consumption	P102,S	DVTP,P,GTP
ZONE	Calculates zone requirements	QP,QH,QT,PVL	QPZ,QHZ,QTZ, PVLZ
SAT	Calculates all hour requirements	EL,DV,P,GTP,GTV, QT,QH,QK,QP	ELS,DVS,PS,GS, QTS,QHS,QKS,QPS
DAN	Calculates all day requirements	ELS,DVS,PS,GS, QTS,QHS,QKS,QPS	ELD,DVD,PD,GD, QTD,QHD,QKD,QPD
MJ	Calculates all month requirements	ELD,DVD,PD,GD, QTD,QHD,QKD, QPD	ELM,DVM,PM,GM, QTM,QHM,QKM, QPM
GOD	Calculates all annual requirements	ELM,DVM,PM,GM, QTM,QHM,QKM	ELG,DVG,PG,GG, QTM,QHM,QKM, QPM
OBL	Calculates the data for cloudy days within a month		
VE	Calculates the data for sunny days within a month		

Nomenclature

M	month
D	day
S	hour
Z	zone
TO	ambient temperature
FIO	relative humidity
TVT	wet bulb temperature
TS	river water temperature
FVE	number of sunny days
FOB	number of cloudy days
QP	zone load
GZ	amount of air
QT	heating load
QH	cooling load
QK	condenser load
RV	number of water chillers in work
EL	electrical energy consumption
DV	fresh and make-up water consumption
P	steam consumption
G	water consumption for steam and hot water boiler plant

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Table 2 Annual requirements

Supplier	Data	Alternative			
		1-2.1	1-2.2	1-2.3	1-2.5
Hot water boiler plant	max. capacity $\times 10^4$ kW	0.46	0.46	0.46	0.46
	annual fuel requirements $\times 10^7$ Nm^3	0.445	0.445	0.3	0.445
	annual elec. energy requirements $\times 10^6$ kWh	1	1	1	1
Steam boiler plant	max. steam requirements t/h	23	23	23	57
	annual make-up water requirements $\times 10^4$ t	8.4	8.4	8.4	11.62
	annual fuel requirements $\times 10^7$ Nm^3	0.938	0.938	0.938	1.298
	annual elec. energy requirements $\times 10^6$ kWh	0.94	0.94	0.94	1.07
Water chiller plant	max. capacity $\times 10^4$ kW	1.57	1.57	1.57	1.57
	annual make-up water requirements $\times 10^4$ t	7.14	—	7.14	—
	max. elec. energy requirements $\times 10^3$ kW	4.7	4	5	0.8
	annual elec. energy requirements $\times 10^6$ kWh	5.93	5.0 54	6.56	0.3

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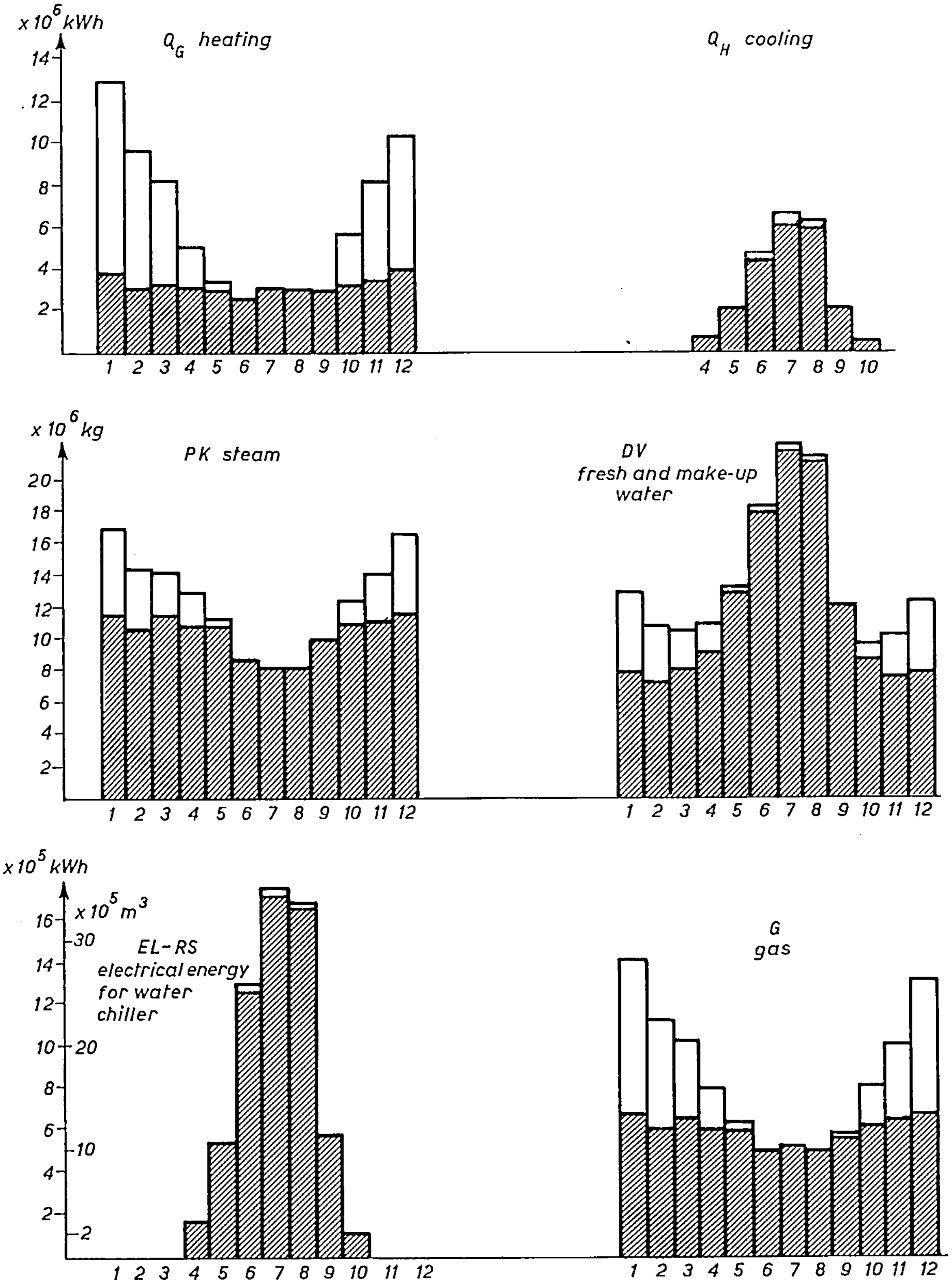

Fig. 4. System requirements.

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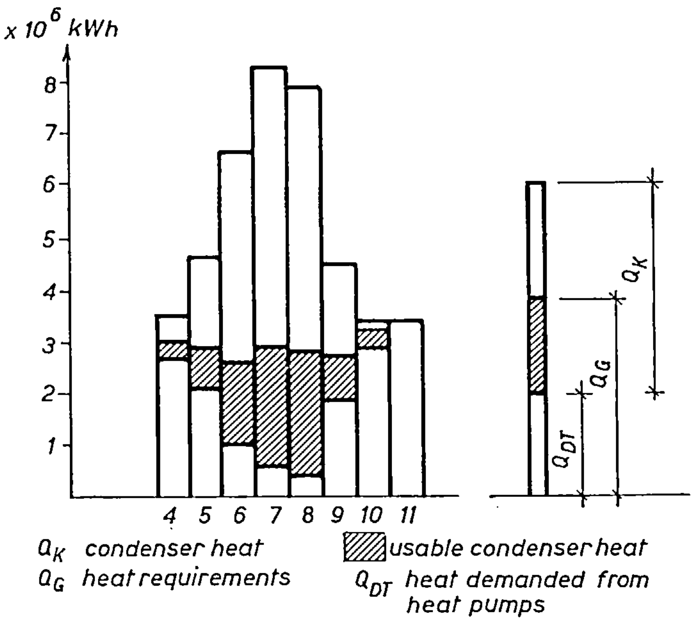

Fig. 5. Heat supply and requirements during a year.

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