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AN ECOLOGICAL COMPARISON OF HEAT SUPPLY SYSTEMS

(Transmitted by the Government of Austria) 1/ 2/

When preparing local and regional energy supply concepts, ecological criteria have to be considered along with managerial and economical aspects.

The air pollution caused by the firing of solid fuels in households can only be reduced by replacing heating systems with high pollutant emissions through less environmentally harmful heating systems. Which heating systems are less environmentally harmful? This paper shall settle this issue for Austrian conditions.

The results of a quantitative ecological comparison of the most common domestic heating systems, i.e. oil, gas and coal heating systems, with electric heating systems and electrically supplied heat pump heating systems are presented.

Assumptions And Marginal Conditions

The last years saw an increasing improvement of domestic combustion technologies. This fact and the sharply reduced pollutant emissions from thermal power generation in Austria are taken into account in this comparative calculation.

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In addition, hydro power makes a substantial contribution to electricity generation in the winter semester, too. Electricity imported during the winter months is "exchange" electricity for electricity generated from hydro power during the summer. These facts result in a countable bonus for all electric heating systems as far as pollutant emissions are concerned.

In order to balance the varying production patterns in electricity generation, 1990 is assumed to be a normal year. The values for fuel consumption of the thermal power stations and for electricity production from hydro power in the individual months of 1990 are available for public electricity supply /1/.

Electricity consumption for electric space heating is to a large extent dependent on the varying heat consumption in the individual months. The electricity consumption of the electric heating systems investigated is assumed to be proportional to the many years' figure of heating degree-days in the individual months.

To the disadvantage of all electric heating systems it is neglected that the pollutants in the flue gas from thermal power plants are released very high above ground level. Therefore their atmospheric dilution is, in general, raised to the power of ten as compared to the dilution of the pollutants resulting from fossil domestic heating "right over the roof".

There is no doubt about the fact that the extent of pollutant concentration in the air (immission concentration) is a measure for medical/hygienical and, in general, ecological concerns. With good reason this fact is answered with the objection that also pollutants released very high above ground level have to return "somewhere" to surface layers. Immission concentration measurements and calculations /2/ during the heating period show by far higher values in densely populated areas than in the immediate and farther surroundings of thermal power stations. As these differences depend on regional conditions and are hard to generalize, this paper does not consider the effects of the noticeably more favourable atmospheric dilution of pollutants from thermal power generation. In this comparison this is to the disadvantage of all electric heating systems.

Now we have to consider the certainly different harmful effects of the various pollutants. Here we can avail ourselves of the standardization possibility offered by the WHO's immission standards /3, 7/. In the following a relative comparison referred to heating with fuel oil is made informing us if and to what extent other heating systems are ecologically better or worse than fuel oil heatings.

Emission factors

The emission factors for domestic heating and thermal power plants are taken from the Energy Report 1984 of the Austrian

Federal Government/4/. In the case of domestic heating, the values for storey and central heating systems are used. With certain restrictions, emission factors for thermal power plants are also taken from the energy report 1984 /4/. In order to meet the strict environmental regulations, thermal electricity generation in Austria is carried out almost exclusively in large modern power stations. Existing smaller power plants only serve for reserve purposes contributing thus only very little to the total power station emissions. Factors of 0.9 for desulphurization and 0.8 for denitrification can be assumed for all coal-fired power stations.

Emission factors for dust also have to be changed as compared to the values in the Energy Report 1984 in accordance with the prescribed minimum separation factor of 99.9 % for 4 kg/TJ (hard coal) and 24 kg/TJ (lignite). Similar environmental protection measures will result in a reduction of SO_2 and NO_x emissions in most of the oil- and gas-fired power stations. Partially they have already been carried out and by 1990 we may expect - for all power stations taken together - an average SO_2 separation of 45 % in oil-fired power stations and an average NO_x separation of 40 % in gas- and oil-fired power stations.

Thus we receive the emission factors for thermal power stations listed in Table 1 on which the calculations are based.

Specific Emissions From Domestic Heating

Through various measures such as

- higher desulphurization degree for fuel oil;
- stove oil heatings and solid fuel boilers were replaced by gas-fired central heatings;
- improvement of boiler efficiency in domestic heating systems;
- heating reduction through improvement of thermal insulation;

pollutant emissions from fossil domestic heating could be reduced in the last decade. This is being considered by assuming a range of values for the average efficiency of domestic heating systems during the heating period (annual operation efficiencies):

Hard coal, lignite, briquette, coke	0.45 ... 0.6
Fuel oil, -light, -extra light	0.5 ... 0.7
Gas	0.55 ... 0.8

In general, a lower value for the efficiency of older heating systems has to be assumed. Modern heating systems show, in general, a high efficiency. Thus the specific emissions of domestic heating referred to the useful energy can be determined in g/kWh - UE (kWh-useful energy), (Table 2).

Share of Primary Energy Sources In Electricity Generation

A calculation of the production of Public Electricity Supply (utilities, without deliveries from industries) was carried out for 1990 /1/. The forecast shows that in normal years 54.3 % of thermal electricity production will derive from hard coal- and lignite-fired power stations. In 1984 this figure only reached 38.3 %. The fuel quantities to be assumed according to this calculation for the individual primary energy sources in 1990 can be seen, split up by months from January to December (1 to 12), in Table 3.

It is assumed that - based on the calorific value - approximately twice as much natural gas as oil is used for thermal electricity production. The division that was chosen between oil and gas employment for electricity production more or less corresponds to the values of the last years. The actual production shares will, however, be largely dependent on energy prices and stock situation at the time.

As referred to the quantity of heat (Table 3) the distribution will be made as follows: approximately one third (32 %) from hard coal, 30.4 % from gas, 22.3 % from lignite and only 15.2 % from oil.

The forecast for the calorific share of electricity production in 1990 is taken from the WIFO energy forecast (WIFO = Institute for Economic Research) /5/. The foreign trade balance (electricity imports minus electricity exports) is attributed to hydro power (see Table 4). By means of the many years' average of the heating degree-days /6/ the monthly shares S_m of electricity consumed for heating (see Table 5) can be determined.

Specific Emissions From Electricity Production For Heating Purposes

Based on the existing data for the forecast year 1990, the specific emissions from electricity production, split up according to pollutants (p), are calculated as a total for the individual fuels (f) and months (m)

$$E_{p,m} = \sum_f EF_{f,p} \cdot QHE_{f,m}/DEC_m$$

$$E_p = \sum_m E_{p,m} \cdot A_m$$

$$E_p = \sum_{f,m} EF_{f,p} \cdot QHE_{f,m}/DEC_m \cdot S_m$$

Key:

QHE .... quantity of heat employed (Table 3)
E ...... specific emissions from electricity production for heating purposes (Table 6)
EF ..... emission factors (Table 1)
DEC .... domestic electricity consumption (Table 4)
S ...... electricity consumption share for heating purposes (Table 5)

The calculation results for the specific emissions from electricity production for heating purposes are listed in Table 6.

Indirect Specific Emissions Of Electric Heating Systems And Indirect And Direct Specific Emissions Of Electrically Supported Heating Systems

The indirect specific emissions of electric heating systems and direct specific emission of electrically supported heating systems (heat pump heating systems) are determined according to the following assumptions: the efficiency of electric direct heating (DH) equals 1, the efficiency of electric storage heating (STH) equals 0.9. The average coefficient of performance of a monovalent heat pump (HP-M) for living space heating amounts to 2.5, for bivalent/alternative (HP-A) this value averages 2.1 and for bivalent/parallel heat pumps (HP-P) this value amounts to 2.0. The last two heating systems cover 30 % and 10 % of the heat demand by means of supplemental heating on the basis of fuel oil light (for specific emissions see Table 2).

The calculation results for the indirect specific emissions of the electric heating systems considered and the indirect and direct specific emissions of the electrically supported heating systems are listed in Table 6.

Comparison Of The Specific Emissions Of Heating Systems

In order to get a general idea of the calculation results, the sums of the specific pollutant emissions are compared (Table 2 and 6). Thus we can see that solid fuels result in total emissions that are substantially higher than the ones from fuel oil- and gas-fired heating systems as well as from electric and electrically supported heating systems. This circumstance is mainly due to their high CO emissions which result from a usually rather incomplete combustion process in the solid fuel boilers.

Fig.1 shows a graphic comparison of the specific emissions (mean values) from oil- and gas-fired as well as from electric heating systems. Striking are the comparatively low totals of the pollutant emissions from electric heating systems. Yet here we have to make the reservation that a useful calculation of the totals could only be possible if all pollutants considered were equally harmful or if all heating systems had the same proportions of the individual pollutants.

Yet one statement can be made: the total of the indirect or indirect and direct specific pollutant emissions referred to the useful energy (space heat) is in the case of electric heating systems lower than in the case of most fossil domestic heating systems. As far as emission totals are concerned, electric heating systems can only be compared to gas heating systems.

According to the performance ranges assumed, the value ranges for fossil heating systems are calculated (e.g. fuel oil light, the high bar in Fig. 1 corresponds to the low efficiency of 0.5, the low bar corresponds to the high efficiency of 0.7).

Relative Ecological Comparison Of Heating Systems

Given the following conditions /7/, an ecological comparison is made:

- There is a linear relationship between the environmental effects of a pollutant and its immission standard (linear dose-effect relationship).

- Different pollutants have identical environmental effects if the actual immission concentrations equal the immission standard as defined by WHO /3/. Then the ratio between the actual emission and the immission standard /3/ that is defined as index of the environmental effects (IE)/7/ equals 1.

- The total of the indexes of the environmental effects of all pollutants from a heating system is a quantitative yardstick for the ecological impact on the biosphere (E). Possible synergetic effects are neglected as no generally valid figures are available at the moment.

- Referred to the useful energy, pollutant emissions from power stations and domestic heating result in equal immission concentrations in ground level air (also see "Assumptions And Marginal Conditions").

- The harmful effects of not further specified hydrocarbons can be neglected or are proportional to the total harmful effects of all other pollutants considered from a heating system.

It is true that all these assumptions correspond to the advanced state of environmental research but they still give the impression of major uncertainties in this ecological comparison. In order to balance possible systematic errors, a so-called "index of relative environmental effects" referred, for example, to fuel oil light, is calculated.

The environmental effects (E) of a heating system is calculated by totalling the indexes of the individual pollutants (IE). The index of relative environmental effects (RE) is the index of a heating system referred to fuel oil light (= 1) (see Table 7). The limit values of the result ranges correspond to the assumptions regarding the efficiency range of fossil heating systems. The indexes of relative environmental effects (RE) of electric systems refer to the upper and lower RE limit values of fuel oil light. The RE values of fossil energy sources, however, are referred to the mean value of upper and lower RE values for fuel oil light.

The calculation results show that the electric and electrically supported space heating systems can very well stand up to an ecological comparison with traditional heating systems. Fig. 2 illustrates the ecological advantages of electric heating systems. Electric systems can only be compared to gas heating systems. As compared to these figures, oil heating systems come off worse by approx. the factor 2.

In addition, it is interesting that when passing from the total pollutant emission values (Fig. 1, Table 2 and 6) to the indexes of relative environmental effects the "ecological order" remains unchanged.

Gas heating systems figure among the bivalent heat pump heating systems whereas oil heating systems have noticeably more ecologically unfavourable effects than electric heating systems. Due to their high carbon oxide emissions, solid fuel heating systems are especially ecologically disadvantageous. Their emissions are approx. 100 times as harmful to the environment as the proportionated emissions from a monovalent heat pump heating system.

These results quantify the already known fact that electricity supply companies has made some comparatively large contributions to the protection of our environment. On the other hand we may also draw the conclusion that more environmental protection measures could be taken in the field of domestic heating. In this context consideration might be given to the fact that the primary energy sources fired in thermal power stations, such as heavy fuel oil and hard coal, have such an inferior quality that their use in fossil domestic heating systems would not be permissible.

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/4/ Energy Report 1984 of the Austrian Federal Government

/5/ WIFO - Institute for Economic Research, Energy forecast up to the year 2000, December 1988

/6/ ÖStZ, Austrian energy supply, annual report 1987

/7/ P.J. Jansen: Evaluation of different heating systems, special edition of the Technical University of Vienna, Metrica publishers, Vienna 1988

Table 1: Emission factors of domestic heating and thermal power stations (kg/TJ)

EMISSION FACTORS kg/TJ		SO-2	NOx	CO	CxHy	DUST
DOMESTIC HEATING :						
HARD COAL		550	50	5500	200	200
LIGNITE		800	20	4000	300	300
BRIQUETTE		350	20	4000	300	100
COKE		500	70	6500	10	50
FUEL OIL - EL	1)	90	50	70	15	5
FUEL OIL - L	2)	135	60	70	10	15
GAS		0	50	60	10	0,1
THERMAL POWER STATIONS :						
HARD COAL		48	50	11	3,4	4
LIGNITE		240	40	11	3,4	24
FUEL OIL		539	129	3,4	6,8	60
GAS		0	115	1	0,5	0,1

1) S-content 0.2 %
2) S-content 0.3 %

Table 2: Specific emissions of fossil energy sources in domestic heating (storey and central heating systems) /4/

EMISSION FACTORS kg/TJ-UE for DOMESTIC HEATING-SYSTEMS

	EFFIC.*)	SO-2	NOx	CO	CxHy	DUST
HARD COAL	0,45	4,40	0,40	44,00	1,60	1,60
LIGNITE	0,45	6,40	0,16	32,00	2,40	2,40
BRIQUETTE	0,45	2,80	0,16	32,00	2,40	0,80
COKE	0,45	4,00	0,56	52,00	0,08	0,40
FUEL OIL - EL	0,5	0,65	0,36	0,50	0,11	0,04
FUEL OIL - L	0,5	0,97	0,43	0,50	0,07	0,11
GAS	0,55	0,00	0,33	0,39	0,07	0,00
HARD COAL	0,6	3,30	0,30	33,00	1,20	1,20
LIGNITE	0,6	4,80	0,12	24,00	1,80	1,80
BRIQUETTE	0,6	2,10	0,12	24,00	1,80	0,60
COKE	0,6	3,00	0,42	39,00	0,06	0,30
FUEL OIL - EL	0,7	0,46	0,26	0,36	0,08	0,03
FUEL OIL - L	0,7	0,69	0,31	0,36	0,05	0,08
GAS	0,8	0,00	0,23	0,27	0,05	0,00

*) annual operation utilization degrees

Table 3: Fuel employment and quantity of heat in thermal electricity production in a normal year, forecast 1990

FUEL		LIGNITE	HARD COAL	GAS *)	OIL *)	TOTAL
HEAT CONTENT OF FUEL		12.5 TJ per 1000 t	28.5 TJ per 1000 t	36.2 TJ per Mio.m3	36.2 TJ per Mio.m3	
MONTH:	1	3938	6441	4947	2474	17800
	2	3600	5444	4151	2075	15270
	3	2925	5672	3017	1508	13122
	4	1350	1226	2220	1110	5906
	5	338	0	2124	1062	3523
	6	0	0	1882	941	2824
	7	0	0	2051	1026	3077
	8	0	0	2172	1086	3258
	9	1913	1995	1641	821	6369
	10	3600	3221	2341	1170	10332
	11	3488	5672	3210	1605	13974
	12	3600	5900	4030	2015	15545
TOTAL		24750	35568	33787	16893	110998
PERCENT		22,3	32,0	30,4	15,2	100,0

*) approximately twice as much natural gas as oil is used for thermal electricity production (forecast 1990)

Table 4: Electricity production forecast (GWh) for the normal year 1990 (Public Electricity Supply)

MONTH	THERMAL-POWER	HYDRO-POWER	FTB*)	ELECTR. CONSUMPTION
1	1750	2200	230	4180
2	1500	2060	220	3780
3	1270	2390	220	3880
4	600	2670	120	3390
5	380	3380	-440	3320
6	310	3500	-480	3330
7	340	3410	-480	3270
8	360	3280	-420	3220
9	620	2680	-110	3190
10	1000	2420	190	3610
11	1350	2270	210	3830
12	1520	2240	290	4050
TOTAL	11000	32500	-450	43050

*) Foreign trade balance = electr. imports minus exports

Table 5: Monthly share S_m of electricity consumption for heating purposes, calculated from the many years' average of the heating degree-days /6/

MONTHS	HEATING DEGREE-DAYS (many years average)	MONTHLY SHARE Sm
1	692	0,1701
2	581	0,1428
3	527	0,1295
4	337	0,0828
5	172	0,0423
6	74	0,0182
7	44	0,0108
8	48	0,0118
9	116	0,0285
10	327	0,0804
11	502	0,1234
12	648	0,1593
total	4068	1

Table 6: Specific emissions (E) from electricity production for heating purposes and indirect and direct specific emissions of electrically supported heating systems (g/kWh-N)

EMISSIONS in mg/kWh-UE		SO-2	NOx	CO	CxHy	DUST
	X=(Electricity)	485,89	251,33	24,13	10,2	50,45
	Y=(FUEL OIL-EL)	648	360	504	108	36
	Formulas used:					
E-DH	X	485,89	251,33	24,13	10,20	50,45
E-STH	X/0.9	539,88	279,26	26,81	11,33	56,06
HP-M	X/2.5	194,36	100,53	9,65	4,08	20,18
HP-P	(0.9*X/2.0)+0.1*Y	283,45	149,10	61,26	15,39	26,30
HP-A	(0.7*X/2.1)+0.3*Y	356,36	191,78	159,24	35,80	27,62
OIL-EL		648	360	504	108	36
OIL-L		972	432	504	72	108
GAS		0	327	393	65	1

Table 7: Calculation of the index of relative environmental effects (RE)

CALCULATION of the INDEX OF ENVIRONMENTAL EFFECT (IE), the ENV. EFFECT (E=sumIE) and the RELATIVE ENV. EFFECT (RE) refered to FUEL-OIL - L in (g/kWh-UE)/(mg/m3 WHO - immission-limit)

	SO-2	NOx	CO	DUST	E	RE
WHO-limit	0,125	0,12	0,15	11,5		
	INDEX OF ENVIRONMENTAL EFFECT (IE)				E	RE
upper value refer to RE<OIL-L(l)>						
E-DH	3,887	2,094	0,161	0,004	6,147	0,551
E-STH	4,319	2,327	0,179	0,005	6,830	0,613
HP-M	1,555	0,838	0,064	0,002	2,459	0,221
HP-P	2,268	1,242	0,408	0,002	3,921	0,352
HP-A	2,851	1,598	1,062	0,002	5,513	0,494
lower value refer to RE<OIL-L(u)>						
E-DH						0,394
E-STH						0,438
HP-M						0,158
HP-P						0,251
HP-A						0,353
upper value (low efficiency) refer to RE<OIL-L(a)> *)						
OIL-EL	5,184	3,000	3,360	0,003	11,547	0,863
OIL-L	8,640	3,600	3,360	0,009	15,609	1,167
GAS	0	2,725	2,620	0	5,345	0,399
H.COAL	35,2	3,3	293,3	0,139	332,006	24,815
LIG	51,2	1,3	213,3	0,209	266,075	19,887
BRI	22,4	1,3	213,3	0,070	237,136	17,724
COKE	32,0	4,7	346,7	0,035	383,368	28,653
lower value (high efficiency) refer to RE<OIL-L(a)> *)						
OIL-EL	3,703	2,143	2,400	0,002	8,248	0,616
OIL-L	6,171	2,571	2,400	0,007	11,150	0,833
GAS	0	1,873	1,801	0	3,675	0,275
H.COAL	26,4	2,5	220,0	0,104	249,004	18,611
LIG	38,4	1,0	160,0	0,157	199,557	14,915
BRI	16,8	1,0	160,0	0,052	177,852	13,293
COKE	24,0	3,5	260,0	0,026	287,526	21,490

*) average(a) = RE<OIL-L(u)> + RE<OIL-L(l)> / 2

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Fig. 1: Comparison of specific emissions from heating systems

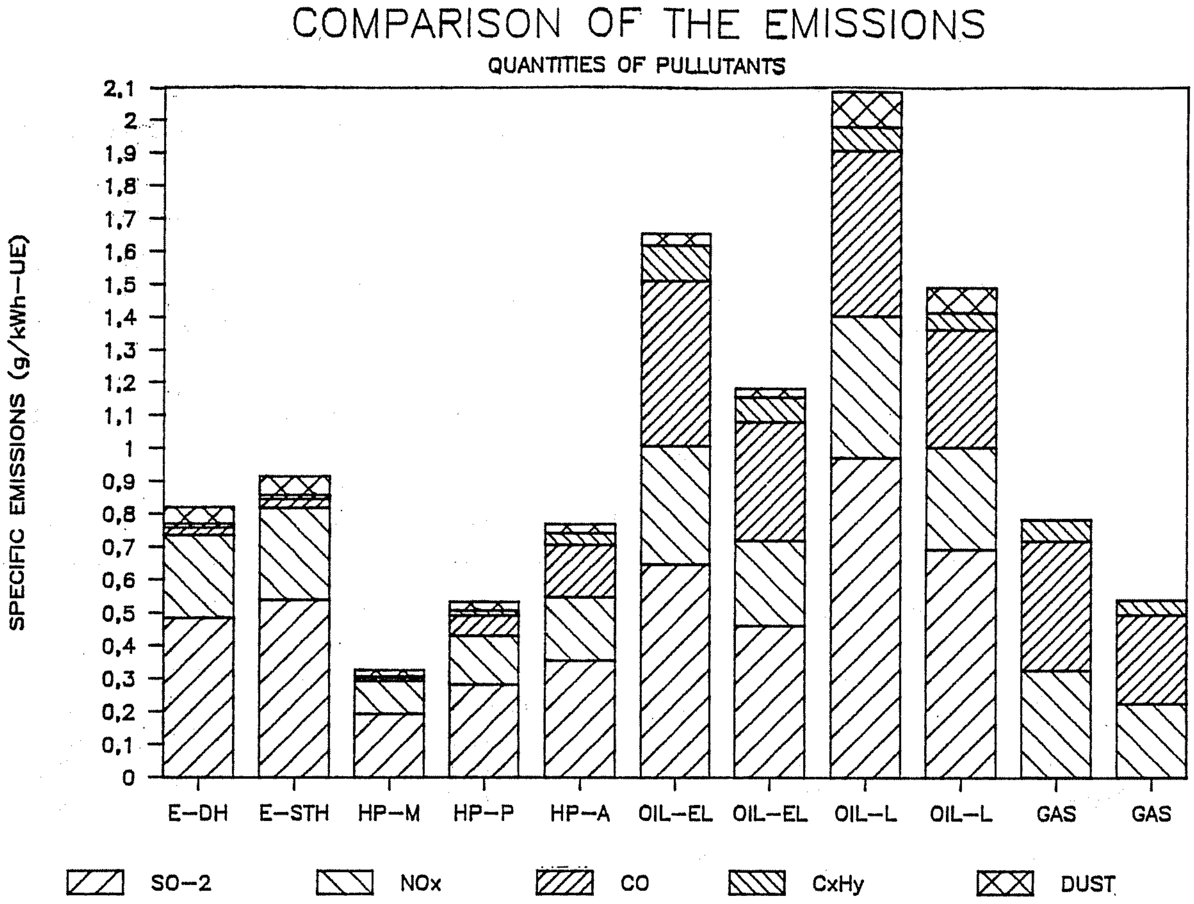

Fig. 2: Comparison of the indexes of relative environmental effects, referred to fuel oil light.