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Energy consumption and potential energy savings in old school buildings

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Abstract

Energy and indoor environmental audits of energy consumption and indoor air quality were taken in 24 school buildings in Slovenia. The audits show that these buildings are high energy consumers and have poor indoor air quality, as expressed by 60% of the surveyed pupils. This article deals with energy consumption in the analysed schools. The nominal heating power of boilers, and heat exchangers, which are used in district heating, show a 57% overcapacity. The heat losses of the school buildings are 89% higher than the recommended values. According to our analysis of the possible measures to improve the situation in the school buildings, it will not be possible to ensure rational energy use and good indoor air quality with low investment costs. Should we change from hot-water heating systems and natural ventilation to energy efficient blown air systems with which one device provides the comfort of both heating and air conditioning?

Keywords: Energy audit; School buildings; Energy number; Energy saving

1. Introduction

High energy consumption is one of the serious problems in the world today. Recently, this question has taken on not only economic, but also ecological and social importance. The most important environmental issue is CO_2 emissions. In the future, the external costs of the environment will be included in the price of energy and energy efficient buildings will be very important. Energy audits are one of the most useful tools for increasing the energy efficiency in European countries. In Slovenia, a program of energy audits was developed under an ongoing project entitled: 'Stimulation of projects for efficient energy use in industry and buildings', which was begun in 1992 and is supported by the state government. The total cost of the energy auditing program in Slovenia up to the present is about one million ECU. The possible energy savings for the industrial sector will be, on average, 15% or 12%, using measures where the pay-back period is shorter than three years. The possible energy savings in public buildings is about 31%, or 7% when the pay-back period is shorter than three years.

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2. Energy audit

This analysis of 24 school buildings in both towns and the countryside of Slovenia shows real energy consumption [1,2] and indoor air quality [3]. The analysed school buildings (characteristics shown in Table 1) do not fall within the range of accepted values of the Slovenian codes for energy use [4]. Energy audits of the school buildings were taken from 1995 to 1996 following the methodology for taking energy audits [5,6].

2.1. Heat loss in buildings

The allowed heat loss of buildings heated over 18°C must be lower or equal to the demand value of the standard (Eq. (2)). The standard also shows the sharpest demand as a recommended value (Eq. (4)). For every school building, the actual heat losses were compared with the allowed one (Fig. 1). The average allowed heat loss of 24 W/m^3 is 63% more than the actual heat loss, which is, on average, 38 W/m^3. Allowed heat losses are highest in the schools in the countryside.

$$\Phi_C = \Phi_{TR} + \Phi_V \quad (1)$$

$$\Phi_C \leq \Phi_{C.S} \quad (2)$$

$$\Phi_{C.S} = (7 + 14 f_o) + \left(\frac{n}{3600} \rho c_p (t_i - t_e)(1 - \eta)\right) \quad (3)$$

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Table 1
Characteristics of analysed school buildings

Name of school →	Sign	Built/adaptation	A_{he} (m^2)	V_{he} (m^3)	n_{pup}	Heating device	Nominal heat power (kW)	Regulation	Ventilation
Tone Čufar →	A	1960/1989	4409	14926	576	district heating	674.07	zones	natural
Prule →	B	1911/1988	6159	24180	700	boiler/gas	2 × 582	centralized	natural[a]
Bežigrad →	C	1938/1996	7709	26689	1000	district heating	1086	centralized	mechanical[b]
Poljane →	D	1906/1994	4700	19453	1200	district heating	604.3	centralized	mechanical[c]
Technical school, Trbovlje →	E	1961/1990	1376	4780	180	district heating	163.4	centralized	natural
Krško →	F	/1984	1250	4342	261	boiler/oil	150/250	handl.	natural
Metlika →	G	1965/1985	2965	12239	725	boiler/oil	2 × 520	centralized	natural
Franja Albrehta →	1	1959	3630	12200	607	boiler/oil	1163 + 930	centralized	natural
Mekinje →	2	1885/1950	338	1400	89	boiler/oil	2 × 50	centralized	natural
Nevlje →	3	1963/1988	659	6200	79	boiler/oil	2 × 151	centralized	natural
Vranja peč →	4	/1948	162	456	15	boiler/oil	[d]	centralized	natural
Tunjice →	5	1962	320	1500	45	boiler/oil	116	centralized	natural
Toma Brejca →	6	1943/1981	2670	11654	661	boiler/oil	[d]	centralized	natural
Loke →	7	1945/1988	268	800	37	boiler/oil	58	centralized	natural
Motnik →	8	1939/1991	460	1840	27	boiler/oil	48	centralized	natural
Sela →	9	1932/1988	349	1025	29	boiler/oil	80	centralized	natural
Šmartno →	10	1948/1973	372	1240	50	boiler/oil	75	centralized	natural
Zgornji Tuhinj →	11	1902/1983	318	1550	68	boiler/oil	98	centralized	natural
27. Julij →	12	1874/1983	1274	4510	55	boiler/oil	260	centralized	natural
Marije Vere →	13	1967/1986	3540	10180	740	boiler/oil	2 × 930	centralized	natural
Stranje →	14	1947/1971	2225	9080	385	boiler/oil	2 × 360	centralized	natural
Gozd →	15	1948/1992	374	1105	27	boiler/oil	56	centralized	natural
Moste →	16	1956/1982	1560	6600	324	boiler/oil	290	centralized	natural
Komenda →	17	1969/1993	4100	12000	600	boiler/oil	2 × 400	centralized	natural

[a]Only kitchen; [b]only gymnasium, dressing-room, kitchen; [c]only kitchen, lavatory; [d]without labeling.

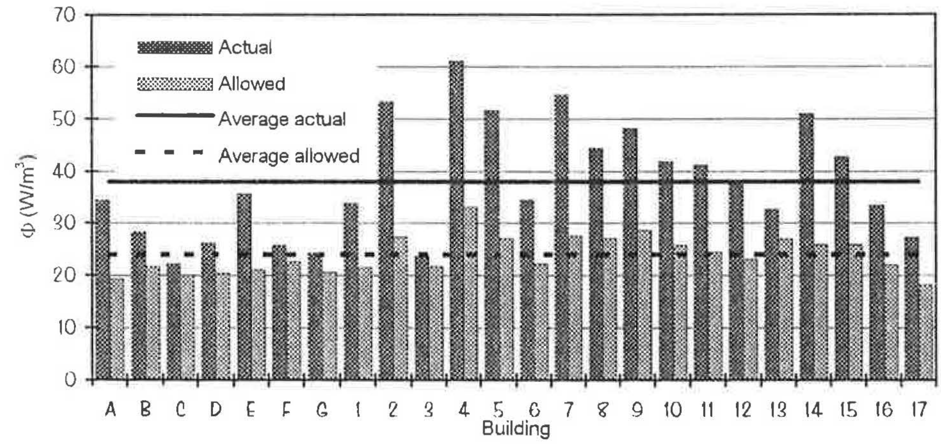

Fig. 1. Actual and allowed heat losses of the analysed buildings.

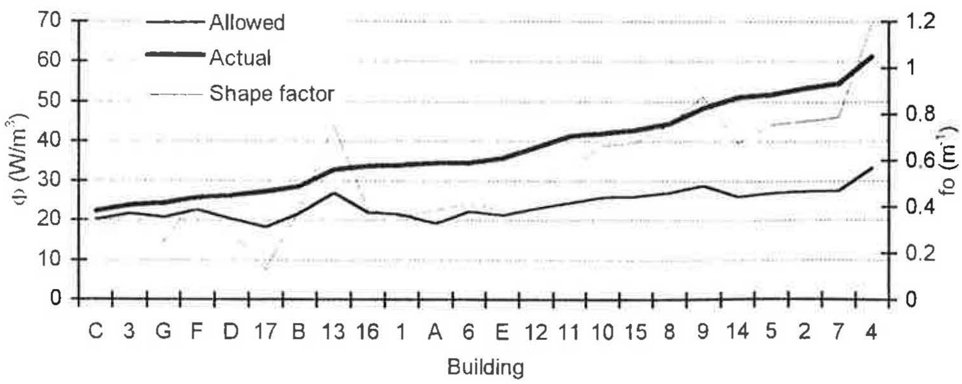

Fig. 2. Correlation between building shape factor and actual and allowed heat losses in analysed school buildings.

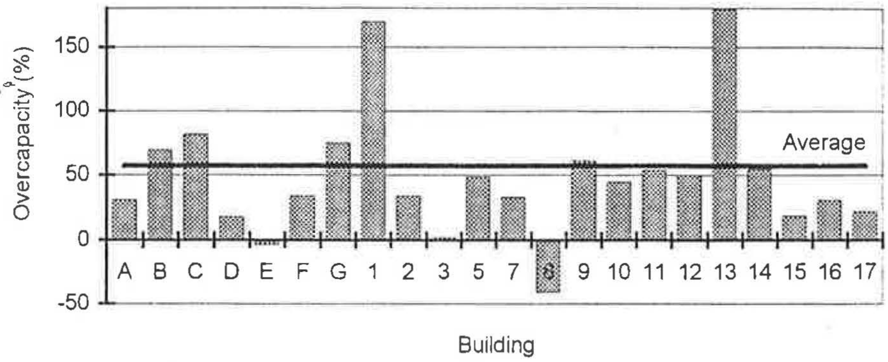

Fig. 3. The overcapacity of built-in heating devices by nominal heat power.

$$\Phi_{C.S} = (5 + 10f_o) + \left(\frac{n}{3600}\rho c_p(t_i - t_e)(1 - \eta)\right) \quad (4)$$

condition: $n \leq 0{,}7$ $\eta = 0$; $n > 0{,}7$ $\eta \geq 0{,}7$; where

$$f_o = \frac{A}{V} \quad (5)$$

The ratio A/V is the building shape factor and has an important influence on the allowed heat losses of the building (Fig. 2), since the shapes and sizes of the analysed school buildings were very different. For example, small buildings with a large external building area have a higher building shape factor since they have a small inside volume (building 4) in comparison with larger objects (building C).

2.2. Overcapacity of the boilers and heat exchangers

We are assuming that efficient energy use by the installed heating power of the device should be 10% lower than required. There are two key characteristics of the analysed buildings: one is the overcapacity of the boilers and the second is overcapacity of the heat exchangers in district heating stations. This creates additional investment costs since the devices are less efficient, thereby consuming more fuel and causing more pollution of the environment. The average overcapacity of built-in heating devices is 57% (Fig. 3). The reason for this overcapacity is poor building design, construction methods in the past, and a deficit of knowledge and experience.

Table 2
Actual energy consumption for heating, sanitary water and lighting

Building	Heating (kWh/m^2a)	Electricity (kWh/m^2a)	Both (kWh/m^2a)	Heating (kWh/m^3a)	Electricity (kWh/m^3a)	Both (kWh/m^3a)	Heating (kWh/pup · a)	Electricity (kWh/pup · a)	Both (kWh/pup · a)
A[a]	129	22	151	38	6	44	987	168	1155
B[a]	153	1	154	39	0.3	39	1346	10	1356
C[c]	117	16	133	34	5	39	550	123	673
D[a]	147	16	163	36	4	40	576	63	639
E[d]	141	3	144	41	1	42	1079	23	1102
F[a]	84	15	99	24	4	28	402	71	473
G[b]	234	18	252	57	4	61	957	74	1031
1	179	15	194	47	4	51	1070	88	1158
2	240	11	215	88	3	71	912	41	953
3	209	22	232	70	7	77	1747	185	1932
4	296	14	310	105	5	110	3200	151	3351
5	228	6	234	71	2	73	1624	42	1667
6	188	22	210	48	6	54	759	90	849
7	257	16	273	86	5	91	1860	116	1975
8	220	4	224	55	1	56	3752	70	3822
9	338	11	348	109	3	113	1066	127	4192
10	218	22	240	65	7	72	1624	165	1789
11	214	12	225	44	2	46	1000	54	1054
12	187	21	209	59	7	66	4338	496	4835
13	144	32	176	35	8	43	690	154	844
14	228	22	248	47	5	52	1305	127	1432
15	176	10	187	55	3	58	2444	142	2586
16	211	44	255	50	10	60	1020	211	1231
17	89	8	97	30	3	33	2200	201	2401

[a]1992/1993, [b]1992/1996, [c]1993/1994, [d]1994, other data are for average energy consumption in the period 1991/1994.

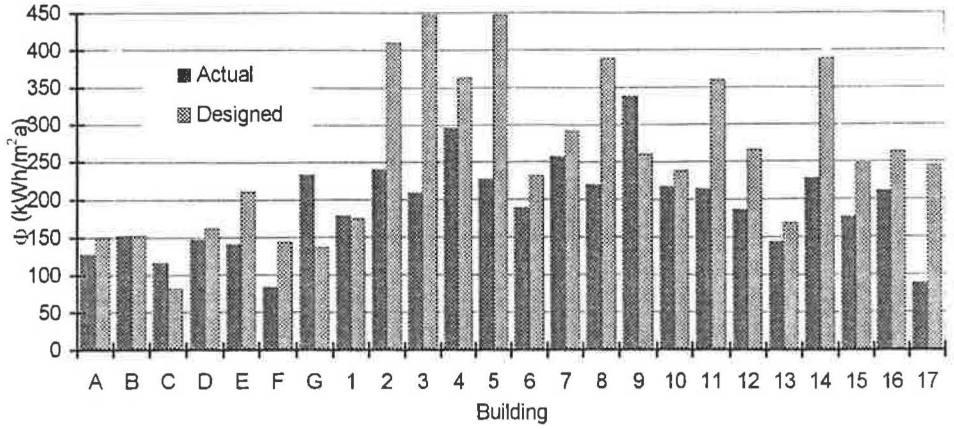

Fig. 4. The energy consumption for heating per square meter of building area at actual and designed conditions.

2.3. Heat and electricity use

In Table 2, the energy use for heating, sanitary hot water, and lighting is presented. On average, the total energy consumption per school building is 192 $kWh/m^2 \cdot a$ (Fig. 4), 54 $kWh/m^3 \cdot a$ (Fig. 5) or 1646 $kWh/pupil \cdot a$ (Fig. 6). The actual energy needs are less than was estimated in the project design. Up to 50% of total heat losses are expected to occur via ventilation which were calculated by standard DIN 4701 for windy regions.

The reasons for the energy losses are as follows: buildings envelopes are not sufficiently thermal-insulated (thermographic analysis), the windows are not tightly fitted. The ventilation is natural and uncontrolled. The heating system is without or with deficient automatic regulation and not zoned. The boilers are old and less effective. The

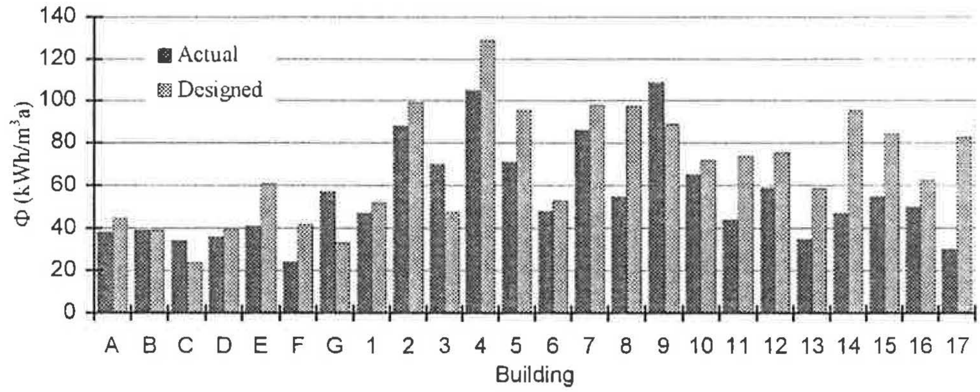

Fig. 5. The energy consumption for heating per unit of volume of building at actual and designed conditions.

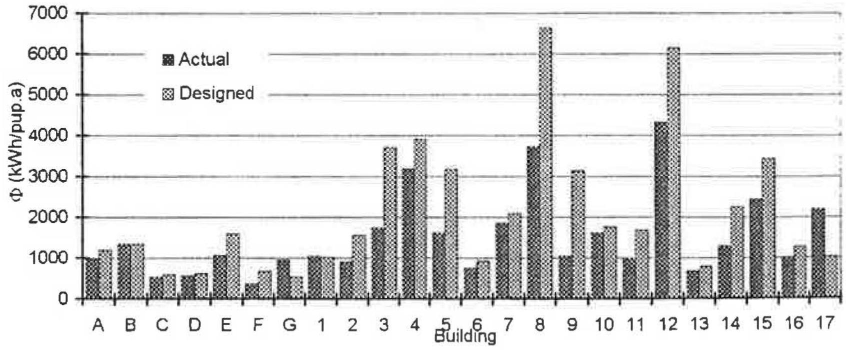

Fig. 6. The energy consumption for heating per pupil at actual and designed conditions.

Table 3
Heating energy numbers of school buildings

Building	E_V (kWh/m³a)	E_A (kWh/m²a)	E_{PUP} (MWh/pup · a)	Building	E_V (kWh/m³a)	E_A (kWh/m²a)	E_{PUP} (MWh/pup · a)
A	48.6	164.5	1.26	6	53	231.2	0.93
B	47.8	187.6	1.65	7	97.8	291.9	2.11
C	37.9	131	1.01	8	97.4	389.5	6.64
D	45.4	187.9	0.74	9	88.9	261	3.14
E	64.2	180	1.71	10	71.6	238.7	1.78
F	48.3	167.8	0.8	11	73.7	359.4	1.68
G	38.2	157.6	0.64	12	75.3	266.4	6.17
1	52	174.6	1.04	13	58.6	168.6	0.81
2	99.1	410.5	1.56	14	95.4	389.2	2.25
3	47.6	447.5	3.73	15	84	248.2	3.44
4	129	363.2	3.92	16	62.3	263.4	1.27
5	95.5	447.7	3.18	17	82.7	244.9	1.04

systems are often unbalanced and heaters do not use thermostatic valves. Energy saving lighting is not used. The same heating zone applies to both school classrooms and the flat of the caretaker. Maintenance of the systems is not always professional supported.

All of this is reflected in inadequate indoor air quality, despite the fact that the windows are not tightly fitted. Room air temperature is too high during classes. The air shortly after the beginning of the lessons is of unsuitable quality, the concentration of the CO_2 is >4000 ppm. Thus, the air is stuffy and irritating [7].

2.4. Energy number

The energy number is the index for rational energy use in buildings (Eq. (6)). The average value of the energy number for heating is 267 kWh/m² · a or 71 kWh/m³ · a. However, energy consumption is higher in comparison with neighbouring countries [8]. Energy efficient school buildings have an energy number from less than 112 kWh/m² · a, to 196 kWh/m² · a. This is also the range in which we can talk about an acceptable use of energy. The energy number per pupil should not exceed 1MWh during the heating season, in our case the average value is 2.17 MWh. The heating energy numbers (Table 3) show that in 75% of the analysed school buildings a huge amount of energy can be saved.

$$E_A = \frac{\phi}{A}\ E_V = \frac{\phi}{V}\ E_{PUP} = \frac{\phi}{n_{pup}} \qquad (6)$$

3. Conclusion and recommendation

There are three key places to implement energy saving measures: on the building envelope, on the heating devices and systems, and with organisational measures. The pay back period for investments in energy measures of the buildings can be: short term with pay-back period less than five years, middle term pay-back period during five and ten years, and long term with pay-back period longer than ten years. The cost-effectiveness of each measure has been investigated. From the energy point of view, the most important measures, necessary in 83% of buildings, are the insulation of the envelope of buildings, and replacement of windows. From the economic point of view, replacing the

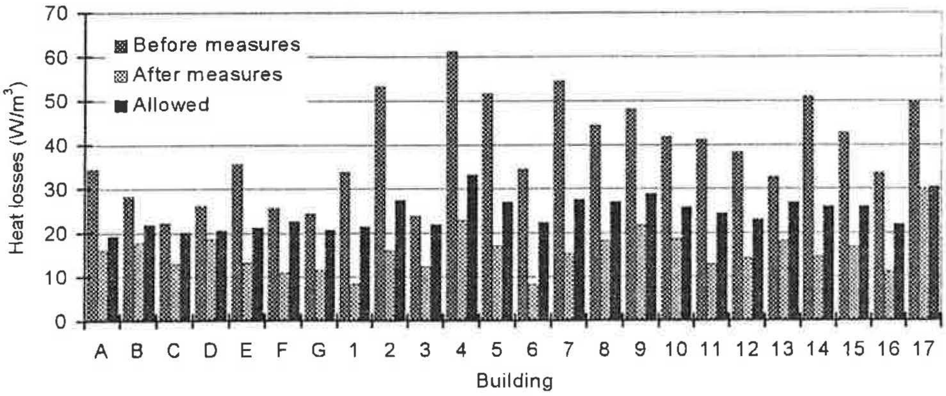

Fig. 7. Comparison of the heat losses before and after realisation of the measures with allowed values.

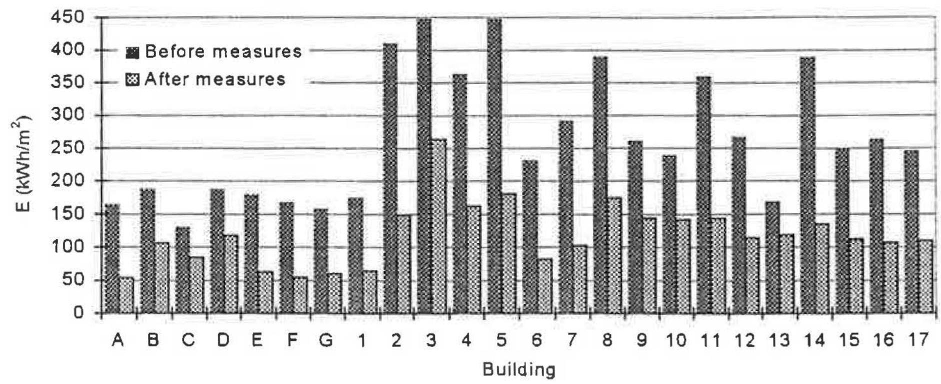

Fig. 8. Comparison of the energy heat number before and after realisation of the measures.

windows is suitable since heat transmission losses are reduced by 7% and ventilation losses as well. Replacing windows means that total heat losses are reduced by 20%. On the other hand, improving window fittings makes the indoor air quality worse [7,9]. The dilemma is whether to reconstruct the heating and the ventilation system separately or to install an energy efficient air heating system with the necessary volume of ventilation air. With the blown air system we can provide heating and cooling, as well as improved indoor air quality.

A comparison the total heat losses and heating energy number before and after the measures should be carried out and is shown in Figs. 7 and 8. The increasing need for energy also involves saving and rational use. In Slovenia, there is a proposal for narrowing the criteria for the thermal insulation of the buildings. The recommended standard value will become the allowed value. Buildings which satisfy the narrower criteria for heat losses (Eq. (7)) will become energy efficient buildings and will be given extra financial support by the state.

$$\Phi_{TR,S} \leq (3 + 5{,}5 f_o) \quad (7)$$

4. Definition of terms

A	area of the building (m^2)
c_p	specific heat at constant pressure (J/kgK)
E_A	energy number per unit area where the heat is lost (kWh/m$^2\cdot$a)
E_{PUP}	energy number per student (kWh/pup $\cdot$ a)
E_V	energy number per unit of volume closed by the area A (kWh/m$^3\cdot$a)
f_o	shape factor of the building (m^{-1})
n	exchange of air (h^{-1})
t_i	indoor design air temperature (°C)
t_e	outdoor design air temperature (°C)
V	volume of the building (m^3)
η	heat exchange efficiency for return air heat
ρ	air density (kg/m^3)
ϕ	consumption of the energy in heating season (kWh)
ϕ_C	whole heat losses of the building (W)
$\phi_{C,S}$	standard specific heat losses (W/m^3)
ϕ_{TR}	heat losses of the building by conduction (W)
$\phi_{TR,S}$	allowed standard heat losses by conduction (W/m^3)
ϕ_V	ventilation heat losses (W)

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