5877

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A Low-cost Methodology for Thermal Performance Monitoring of Public Schools in the Lombardy Region

SERGIO ZABOT

Regione Lombardia, Via Soderini 24, Milan (Italy)

SUKHBIR MAHAJAN†

Commission of European Communities Joint Research Centre, 21020 Ispra, Varese (Italy)

ASHOK K. BHARGAVA*, LANFRANCO SOMA and SIMONETTA FUMAGALLI

ENEA FARE, 21020 Ispra, Varese (Italy)

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SUMMARY

A low-cost methodology for the thermal performance evaluation of the public school buildings in the Lombardy Region is presented. The main aim of the evaluation is to determine the energy savings with reasonable accuracy and thus the cost-effectiveness of the retrofit measures.

Hourly data for weather variables, indoor temperatures and humidity, fuel consumption and heat delivered to the building are collected using an automatic data acquisition system (DAS). The infiltration rate was determined using tracer gas (SF_6) technique and the overall conduction heat loss coefficient was determined by the coheating method. Using these measured quantities and hourly data, heat balances are obtained and the effective solar contribution is calculated.

The procedure is illustrated with the Montorfano School monitored data for a ten-day period. For the ten-day period reported here, the solar contributions (including passive and active) make up 18% of the total heat load. Suggestions for improvements to enhance these contributions are presented. The auxiliary heating system efficiency during the reported period is approximately 54%. The cause of this low efficiency is discussed. The analyses of the data presented here indicate that the methodology is simple and quite accurate for policy-making purposes. It is hoped that this monitoring methodology, which makes it also possible to evaluate the contributions of the various energy sources, will be adopted as a standard for future monitoring work in the Lombardy Region.

INTRODUCTION

In 1980 the School Building Service of the Region of Lombardy started a pilot program for energy conservation and solar energy applications in educational buildings. During the period 1981 - 1984 preliminary energy audits were made. Funds were allocated for 26 school buildings for energy-saving retrofit measures. In order to assess the economic as well as technical performance it was felt that some sort of field monitoring should be performed on these buildings. Only the technical performance analyses are presented here. Field evaluation is a must for encouraging the widespread use of solar/ conservation measures in school buildings. Furthermore, field monitoring can give some idea about the reliability of these new techniques.

As a first step a methodology was developed. The main aim of this methodology is to answer the question: how well do the retrofit measures perform, specifically the solar installations? No attempt is made to understand the details of the performance

*On study leave from Ramjas College, Delhi University, India, under ENEA and ICTP Research and Training Program in Italian Laboratories, Trieste, Italy.

†On sabbatical leave from California State University, Sacramento, California, U.S.A.

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mechanisms. The cost and ease of implementation of the methodology were important considerations for the final choice. In the fall 1984, a methodology was developed to monitor the school buildings. The Montorfano School (one of the above mentioned schools) was instrumented in the late fall of 1984. The choice of this site was based on ease of access. Due to the especially bad winter, and other factors beyond our control, very little reliable data became available during the heating season 1984 - 1985.

The proposed methodology is adequate for achieving the above-mentioned goals. It is simple and reasonably low cost for large-scale applications. More specifically for the Montorfano school, the solar air heater was found to be 35% efficient. The overall heating system efficiency during the heating season rarely exceeds 56%. This low efficiency is partly due to an oversized burner system. The solar contributions are 18% (passive 15%, active 3%) of the total heat load for the period reported. The passive contribution is quite reasonable. The building heating system has been assessed in terms of energy savings and further modifications are suggested to improve upon the existing performance.

2. SITE AND BUILDING DESCRIPTION

The Montorfano Elementary School is located about 5 km south-east of the city of Como. The microclimate of this site is quite different than that of the Lake Como region.

The key plan of the school is shown in Fig. 1, and sections of a classroom and corridor with temperature sensor locations are presented in Fig. 2. The school building was constructed with concrete frames. Two classroom wings are built on a gently sloping hillside and are partly below ground level on the corridor side. The section connecting the two wings has two storeys: the ground floor has a custodian's apartment and school offices and the first floor contains the gymnasium. Figure 2(b) shows the arrangement of the ventilation system on the roof.

The major retrofit measures were:

— increased envelope insulation;

— double glazing of the classroom windows, and

— installation of a solar air heater.

Tables 1 and 1(a) list the physical parameters of the school before and after retrofit measures. Table 2 gives information on important parameters of the solar air heater.

3. METHODOLOGY AND DATA COLLECTION

The methodology outlined below is designed to evaluate the thermal performance of the energy conserving/solar retrofit measures in school buildings. Coheating and tracer gas techniques give the conduction heat-loss coefficient (UA) and the infiltration rates respectively. Both of these are standard techniques and are briefly described later in this section. The passive solar gain ($Q_{passive}$) is obtained as follows:

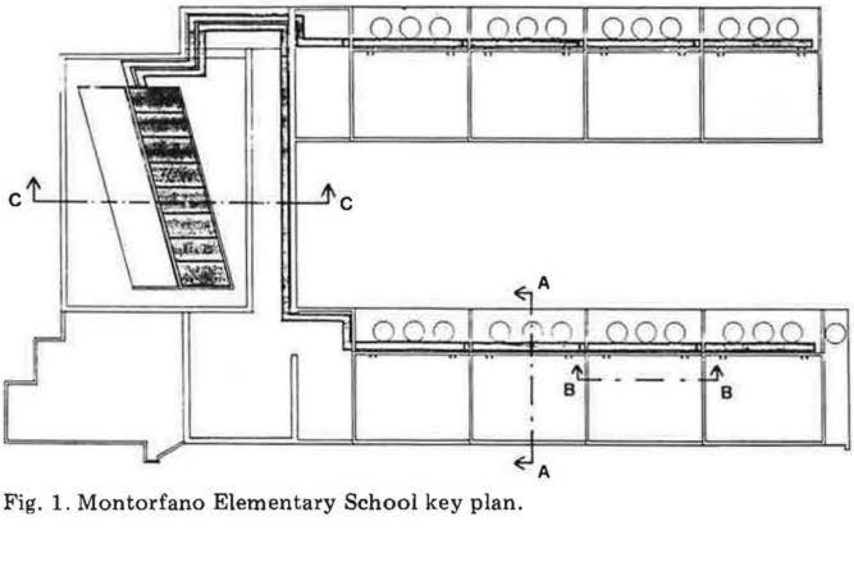
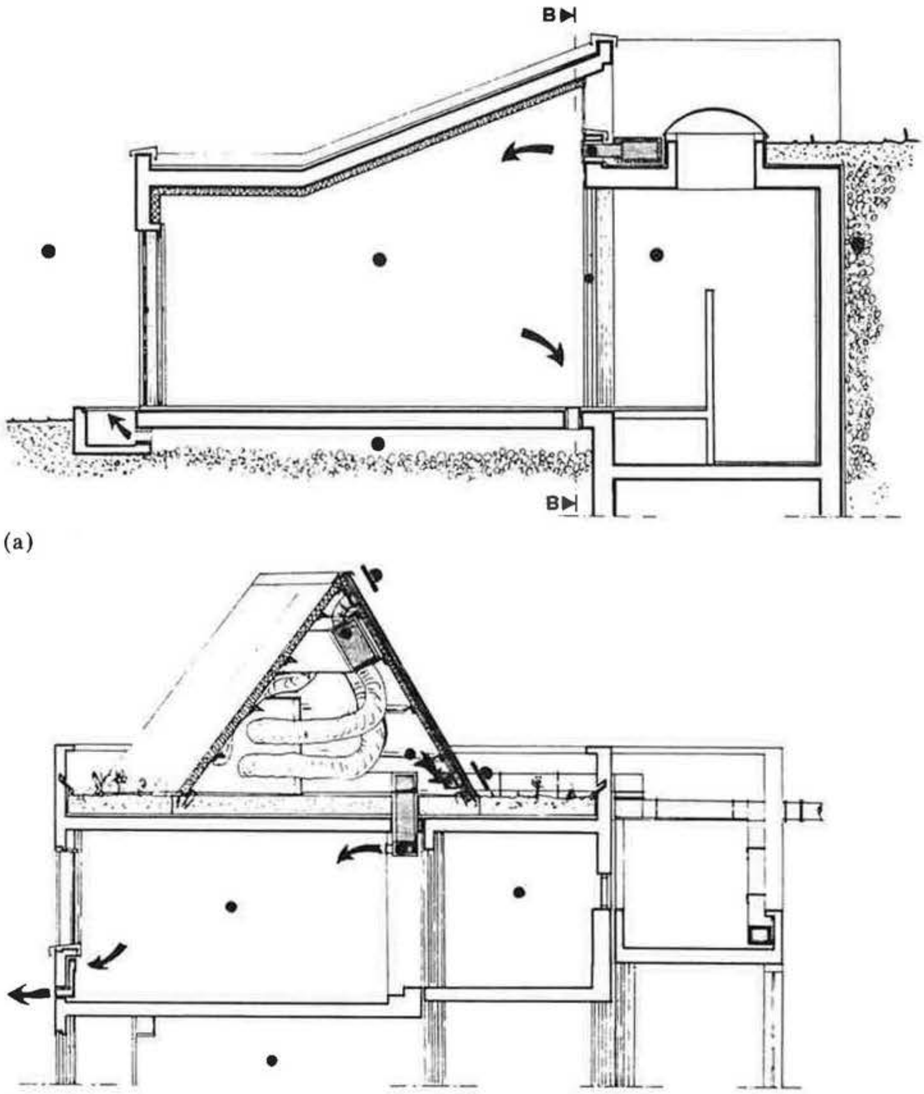


Fig. 1. Montorfano Elementary School key plan.



(a)

(b)

Fig. 2. (a) Section A–A from Fig. 1; ● temperature sensors. (b) Section C–C from Fig. 1; solarimeters, ● temperature sensors.

TABLE 1

Building parameters

	Volume (m^3)	Floor area (m^2)	Glazing area (m^2)
Classroom	141	43	18.5 (West), 6.2 (East)
All classrooms and toilets	1248	348	151 (West), 50 (East)
Corridors	686	212	6.5 (North), 50.6 Sky lights
Auditorium	454	144	26.4 (North),
Main	1181	400	39.4 (North), 26 (West), 34 (South)

Insulation (Internal after retrofit):

Rooms	Roof and walls	4 cm polystyrene + vapor barrier
	Glazing	Second window frame on west side, thermal cut windows + double-pane glass on east side
Auditorium	Roofs and walls	4 cm polystyrene + vapor barrier
	Glazing	Thermal cut windows + double-pane glass on north side.

TABLE 1a

UA values (W/°C) of the various units of the building before and after retrofit

Area/Space		Before	After
Classroom	Outside	209	74
	Floor	56	56
All classrooms and toilet	Outside	1725	760
	Floor	496	496
Corridors	Outside	798	798
	Floor	251	251
Auditorium	Outside	329	155
Rest of building	Outside	652	652
	Floor	317	317

TABLE 2

Solar air heater parameters

Surface area	42.5 m (3 × 14)
Tilt	70°
Glazing	Double (metacrilate)
Orientation	15° east of south

$$Q_{\text{passive}} = Q_{\text{loss}} - Q_{\text{auxiliary}} - Q_{\text{internal}} \quad (1)$$

$$Q_{\text{loss}} = Q_{\text{conduction}} + Q_{\text{infiltration}} \quad (2)$$

Where the Q terms are heat losses/gains attributed to the various mechanisms written as subscripts. The measured indoor–outdoor temperature difference, total heat-loss coefficient (UA) and infiltration rate are used to calculate Q_{loss} assuming steady state conditions. For time intervals which are short (less than a few days) this assumption is not valid, since the time constant of the building is of the order of a few days. However, for periods greater than a week the thermal mass effects are small, and for seasonal performance the errors due to thermal mass should be negligible. The heat delivered to the building consists of:

(a) heat given off by the hot water circulating through the convectors;

(b) the heat supplied by the forced hot air, which is preheated by the solar air heater and if necessary further heated by passing over a hot water radiator,

(c) the passive gain through glazings and opaque surfaces.

The measured values of inlet–outlet temperature differences and the flow rates of hot water and forced air at various points along the flow paths are used to determine the heat delivered by the hot water convectors and the solar air collectors. This information when used in eqn. (1) yields both opaque as well as transparent passive contributions.

The data collection was limited to a level adequate for carrying out the performance evaluation using this methodology as outlined above. This included the measurement of temperatures, insolation, auxiliary heating hot water flow rates, mixing fan on/off time, humidity, wind speed, etc. A complete list of the measured quantities and the instruments used is given in Table 3.

All the measuring instruments were calibrated in the laboratory before field installation. The data was recorded on a cassette tape and later transferred to floppy disks for processing. A schematic layout of data collection and processing is presented in Fig. 3.

Tracer gas measurements

Three sets of tracer gas measurements were made, one each of the following spaces:

— classrooms
— corridor
— auditorium.

In the case of classrooms and auditorium, measurements were made under natural as well as forced ventilation conditions. Tracer gas (SF_6) was injected and allowed to mix for approximately half an hour. Four air samples were obtained at successive intervals of 15 minutes. The concentration of SF_6 was measured using gas chromatography. From the SF_6 concentration decay rates the air exchange rates are obtained. Since the corridor and the rooms as well as the auditorium

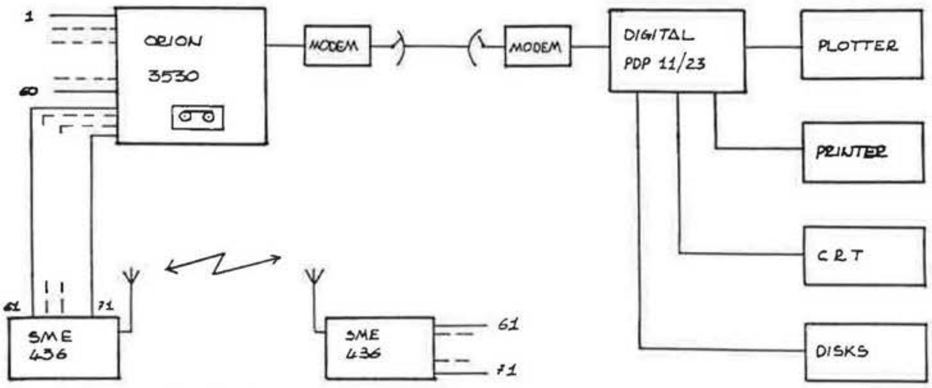


Fig. 3. Schematic of data acquisition system.

TABLE 3

Quantity measured and instruments used

Temperatures	
Rooms 1, 2, 3, 6, 7, 8, 9	All temperatures measured with platinum resistance thermometer (Pt - 100).
Corridor east, corridor west	
Auditorium	
Plenum below room 2	
Ventilation air temperatures in rooms 2 and 7	
Solar air heater — inlet and outlet temperatures	
Auxiliary energy	
Inlet and outlet water temperatures for three lines	Platinum resistance thermometer (Pt - 100)
Water flow rates	Fludistor VD 100
Furnace on/off time	Voltage clamp
Meteorological data	
Solar insolation in the plane of the collector	Epply pyronometer
Ambient temperature	Pt - 100
Wind speed	Lastem C — 1008 anemometer
On/Off time of fans	Voltage clamp

are interconnected, estimates of the air exchanges between these spaces had to be made. Both the measured and estimated air exchange rates are listed in Table 4.

Coheating measurements

The main purpose behind coheating was to check the calculated conduction heat-loss coefficient values with the field measured values. The standard coheating method using electrical heating could not be carried out for the whole school building due to several technical problems. It was therefore decided to perform tests on a classroom and use the results for estimating the conduction heat-loss coefficient for other parts of the building.

The following procedure was used. Electrical resistance heaters replaced the normal auxiliary heating system in classroom 2. The space under the floor was also maintained at a fixed temperature using electrical heaters. The corridor and adjacent rooms were kept at constant temperature using the regular heating system. From the information on temperatures and the electrical auxiliary heating used, the heat-loss coefficient could be calculated. The results are shown in Table 4.

Since the building has a large thermal mass, special care was taken to ensure that the indoor air temperatures were constant. Furthermore, the actual experiment was conducted during a night preceded by many overcast days. In this way, the effects of opaque solar gains and exterior thermal mass effects were minimized.

In order to check the consistency of the procedure two coheating tests, (on February 8, 1985 and on March 18, 1985), were

TABLE 4

Infiltration, coheating and boiler efficiency results

(a) *Infiltration results*

Space	Air changes per hour (ach)	
	Fan off	Fan on
Classroom	0.50	2.78
Corridor	0.50	2.78
Gymnasium	0.50	1.96
Whole building	0.50	
Whole building (excluding rooms and corridor)		2.0

(b) *Coheating results (11-hour test)*

Auxiliary used	=	11.95 kWh
ΔT	=	12.4 °C
$Q_{\text{infiltration}}$	=	176.7 Wh
$UA_{\text{cond.}}$	=	73.7 W/°C

(c) *Boiler efficiency*

Date	Fuel burned (kWh)	Q_{aux} Total (kWh)	Efficiency (%)
Sat 16	2535	1488	58.7
Sun 17	2010	1049	52.2
Mon 18	1931	1044	54.1
Tue 19	1852	1039	56.1
Wed 20	2070	1085	52.4
Thu 21	2555	1349	52.8
Fri 22	2154	1169	54.3
Sat 23	1753	888	50.7
Sun 24	1585	828	52.2
Mon 25	1515	758	50.0
Total	19960	10697	53.6

performed. The results of the two tests are within 5% of each other. Only the results of the second test are presented here.

4. DATA ANALYSIS

The main objective of the data analysis was to calculate the total heat loss, auxiliary energy used (including internal gains) and solar energy contributions. The solar energy contribution consists of two parts, namely energy provided by the solar air collector and passive solar gains. A short description of the procedure used to calculate these quantities is given below.

Total heat loss

The loss of heat from the building is mainly through conduction and infiltration. Both of these heat loss calculations assume steady state conditions. As mentioned before this is a valid assumption for periods longer than the time constant of the building.

The infiltration rates determined from the tracer gas measurements and indoor–outdoor temperature differences are used to obtain the heat loss due to infiltration.

$$Q_{\text{infiltration}} = \text{Volume} \times \text{ach} \times \text{density of air} \times \text{specific heat capacity of air} \times \Delta T \times t$$

$$Q_{\text{infiltration}} = \sum_j V_j R_j \rho_a C_a \Delta T_j t \qquad (3)$$

where

V_j = volume of the jth space

R_j = air infiltration rate for the jth space

ΔT_j = temperature difference between the jth space and outdoors

ρ_a = density of air
C_a = specific heat capacity of air
t = time for which fan is on.

The conduction heat loss calculation was carried out by using the values of heat conduction loss coefficients (UA) as determined by coheating and the measured indoor–outdoor temperature differences.

$$Q_{\text{conduction}} = \sum_j (UA)_j \Delta T_j t \qquad (4)$$

where the summation is over all spaces at different temperatures.

Auxiliary energy

Auxiliary energy is provided by hot water convectors. There are three auxiliary heating hot water lines — line 1 for classrooms, line 2 for the auditorium, and line 3 for integration with the solar air heater. The idea behind the integration line is the following. When the school is in session there is an enhanced air infiltration rate of 2.8 air changes per hour (ach). The outside air at ambient temperature is preheated by passing through the solar air heater and if necessary further heated by passing over line 3. It is forced into the classrooms and gymnasium using a fan. If the temperature of hot air after passage through the solar heater is above 22 °C, line 3 is shut off. Otherwise line 3 is left on to raise the air temperature to 22 °C.

The energy supplied by the hot water was calculated from the information on the inlet–outlet water temperature differences and water flow rates, and the time for which the heating system was on.

$$Q_{\text{auxiliary}} = \sum_\alpha (F_\alpha \rho_w C_w \Delta T_\alpha) t_\alpha \qquad (5)$$

where

α = 1, 2, or 3 for the different hot water lines
C_w = specific heat capacity of water
F_α = flow rate for line α
t_α = total time line α is on
ΔT_α = inlet outlet water temperature difference
ρ_w = density of water

The information on the number of occupants, time of occupancy and the lighting level was used to calculate internal gains.

The final consumption rate and on/off time of the boiler along with auxiliary energy delivered gives the heating system efficiency.

Solar contributions

The measured values of airflow rate through the collector, the inlet–outlet air temperature difference and time the fan is on are used to calculate solar contributions by the solar air collector. An equation very similar to eqn. (5) is used for this calculation. Finally the passive solar contributions are calculated subtractively using eqn. (1). However, any errors made in the calculations of Q_{loss} and Q_{aux} are lumped into the passive contributions.

5. RESULTS AND DISCUSSION

The insolation values, indoor temperatures, outdoor temperatures and auxiliary energy used are plotted in Figs. 7, 8 and 9 for a three-day period (March 23 - 25, 1985). This was a relatively clear period with insolation peaking at 750 W/m^2 (see Fig. 4). There are considerable temperature variations in different parts of the building (see Fig. 5). The classroom temperatures during mornings (when classes are held) are usually 4 - 5 °C higher than those during the rest of the day. The corresponding increased use of auxiliary energy is evident from Fig. 6.

A schematics of the major heat flows for the March 16 - 25, 1985 period is presented in Fig. 7.

The heat balances for the building were performed in three stages. In the first stage only the classroom heat balances were analysed. The results of such an analysis are presented in Table 5. The classrooms have large glazings and thus collect a considerable amount of solar energy. The daily values and totals of Q_{loss}, Q_{int}, Q_{aux}, Q_{passive} and Q_{solar} (collector) are listed in this Table. The listed percentages are with respect to the total load. The solar contribution on a daily basis is not meaningful, because of charging and discharging of the thermal mass. However, the value of 28% (20% passive; 8% active) for the 10-day period is nearly free of thermal mass effects.

The corridors which have strong thermal coupling with rooms receive very little direct solar energy. Table 6 lists the heat balance for the corridors and rooms combined. As expected the solar contributions drop to 15% for the 10-day period. Finally the whole building

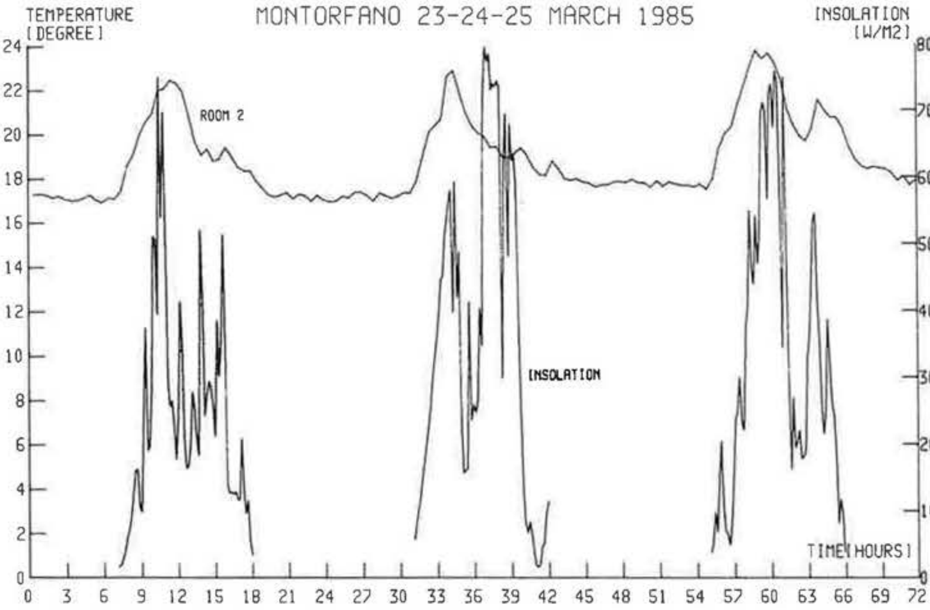


Fig. 4. Insolation on collector plane and classroom 2 temperature.

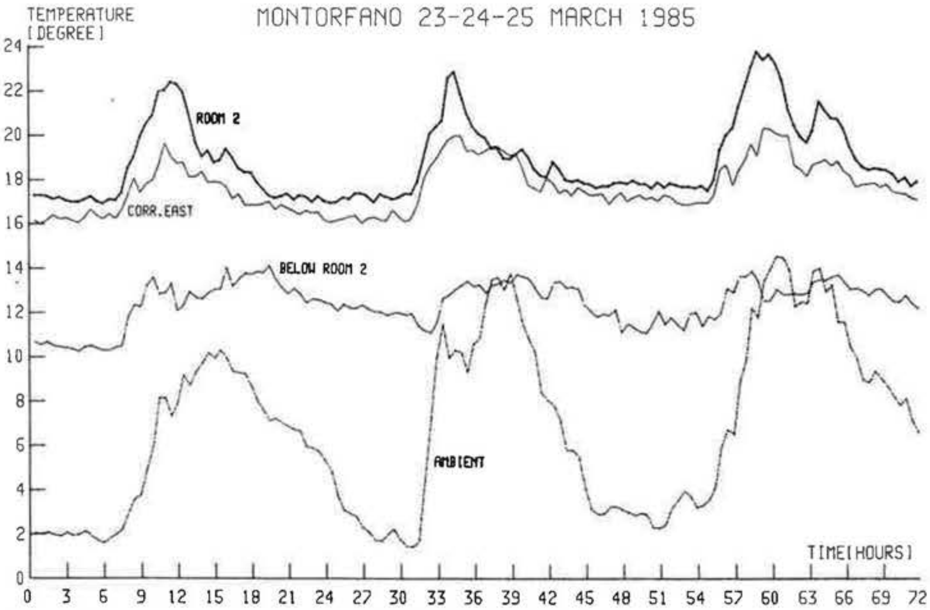


Fig. 5. Temperatures in various parts of the building.

heat balances are presented in Table 7. For the ten-day period the solar contribution is 18% (3% active and 15% passive). The slight increase in solar gains over that for the rooms and corridor case is due to the fact that the main building has considerable south-facing glazing.

The boiler efficiency varied between 50.1% (March 24, 1985) to 58.7% (March 16, 1985). The boiler was sized for the heating requirements before the retrofit measures. Since the retrofit measures reduced the heat load considerably, the boiler operates more intermittently, thus lowering the efficiency. This is quite evident from the data presented (see Table 4). On clear sunny days the heating system efficiency is lower than that on overcast days.

The highest efficiency for the solar air collector system is 50.7% and the average for the 10-day period presented here is 34.6%. This is quite reasonable, especially considering the fact that some of the glazing on the collector panels was cracked. For the clear day the solar air heater system is nearly 40% efficient with instantaneous efficiency as high as 65.7%.

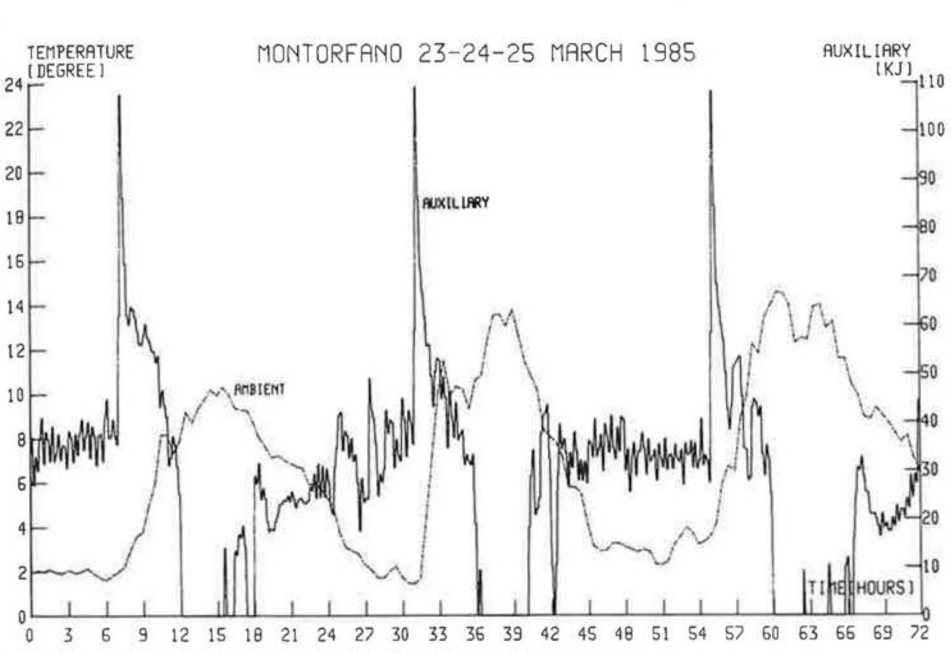


Fig. 6. Ambient temperature and delivered auxiliary energy.

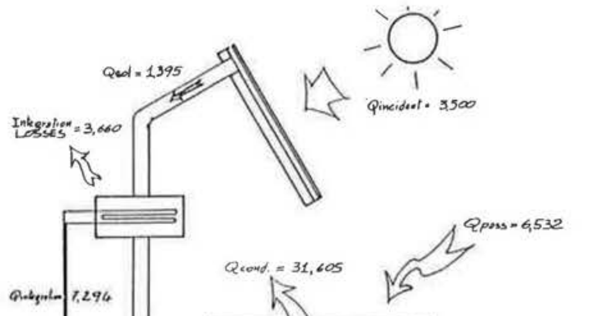


Fig. 7. Montorfano: 10-day energy balance schematics.

The efficiency of this system is higher on a partly clear day than on a totally clear day. The reason for this could be the greater heat loss through the cracked collector glazing on a clear day than on a partly clear day.

To understand the performance of the solar collector, the heat balances for three days are presented in Tables 8 - 10.

The solar contributions to the heating energy requirements are quite reasonable. The original design calculations suggested a use of 130 m^2 of solar air heater collector area. However only 42.5 m^2 of solar air collectors were installed, because of building constraints. The design calculation efficiency was 65%. The discrepancy between the design and measured values of efficiency is attributed to the following factors:

(a) Cracked glazing — leading to larger than design heat losses from the collector.

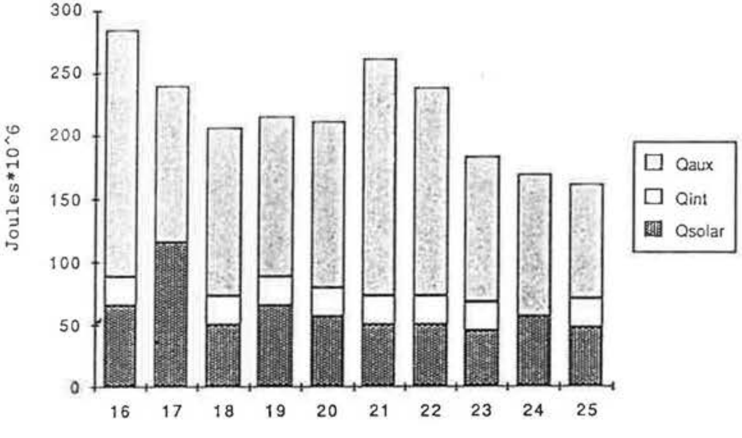
(b) Lower flow rates than design values (design 5547 m^3/h, measured 3462 m^3/h) means outlet–inlet temperature differences are higher than designed and hence there are greater heat losses.

(c) The solar air collector was not used during the total available period of sunshine. It was shut off in the afternoons. In fact the collector is faced 15° east of south to take full advantage of the sunshine before noon.

There is a need to improve upon the operational mode logic for better performance. For instance, the ventilation air should not be passed through the collector on cold overcast days, since this leads to cooling of the air (see Table 8). The integration hot water line was on the roof. To avoid freezing complications it was left on even when the fan was off. This meant a considerable heat was wasted. The problem can be easily rectified by replacing the electrical resistance heater and appropriate controls.

TABLE 5

Classroom 2 heat balance



Montorfano - Classroom 2

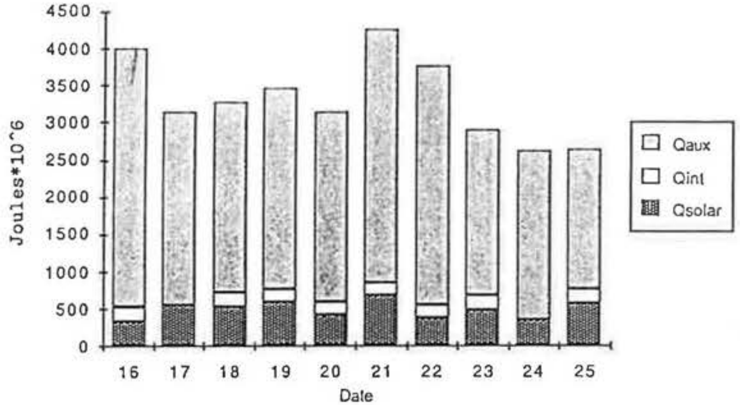
March 1985

Montorfano - Room 2 - March 1985 [JOULES * 10 ¯ 6]

Date	Qloss	Qint	Qaux	Qsolar Pass.	Qsolar Coll.	Qsolar Total	Sol %	Int %	Aux %
Sat.16	285.6	23.1	197.0	65.5	0.0	65.5	23%	8%	69%
Sun.17	240.4	0.0	125.1	76.7	38.6	115.3	48%	0%	52%
Mon.18	207.4	23.1	134.1	42.7	7.5	50.2	24%	11%	65%
Tue.19	215.4	23.1	126.0	32.0	34.3	66.3	31%	11%	58%
Wed.20	211.8	23.1	131.6	36.5	20.6	57.1	27%	11%	62%
Thu.21	261.9	23.1	189.2	49.6	0.0	49.6	19%	9%	72%
Fri.22	237.7	23.1	165.1	41.2	8.3	49.5	21%	10%	69%
Sat.23	183.4	23.1	115.2	29.8	15.3	45.1	25%	13%	63%
Sun.24	168.9	0.0	112.7	28.2	28.0	56.2	33%	0%	67%
Mon.25	161.8	23.1	91.7	28.5	18.5	47.0	29%	14%	57%
TOT.	2174.3	184.8	1387.7	430.7	171.1	601.8	28%	8%	64%

TABLE 6

Rooms and corridor heat balance



Montorfano -
Classrooms & Corridors

March 1985

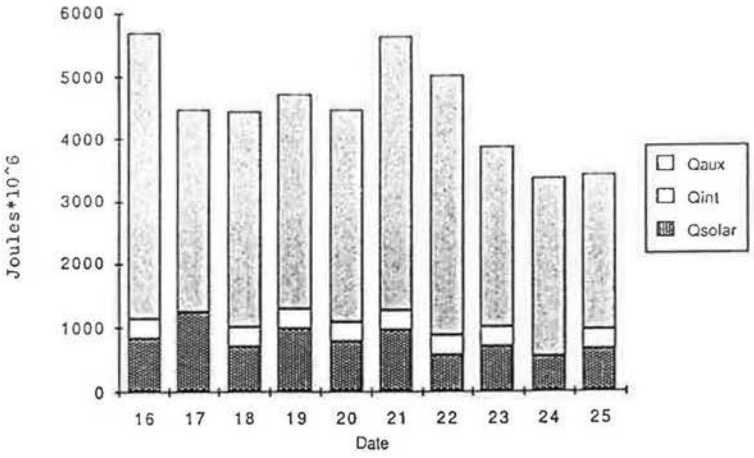
Montorfano - Rooms & Corridors - March 1985 [JOULES * 10 ¯ 6]

Date	Qloss	Qint	Qaux	Qsolar Pass.	Qsolar Coll.	Qsolar Total	Sol %	Int %	Aux %
Sat.16	4003.3	185	3475.8	342.5	0.0	342.5	9%	5%	87%
Sun.17	3134.1	0	2577.8	402.1	154.2	556.3	18%	0%	82%
Mon.18	3275.6	185	2561.7	468.7	60.2	528.9	16%	6%	78%
Tue.19	3461.3	185	2692.3	309.4	274.6	584	17%	5%	78%
Wed.20	3136.6	185	2537.6	271.8	142.2	414	13%	6%	81%
Thu.21	4270.8	185	3417.6	668.2	0.0	668.2	16%	4%	80%
Fri.22	3759.2	185	3203.3	304.7	66.2	370.9	10%	5%	85%
Sat.23	2899.4	185	2221.1	370.9	122.4	493.3	17%	6%	77%
Sun.24	2615.7	0	2267.5	236.1	112.1	348.2	13%	0%	87%
Mon.25	2645.7	185	1891.1	402.9	166.7	569.6	22%	7%	71%
TOT.	33201.7	1480	26845.8	3777.3	1098.6	4875.9	15%	4%	81%

TABLE 8

TABLE 7

Whole building heat balance



Montorfano - Whole Building

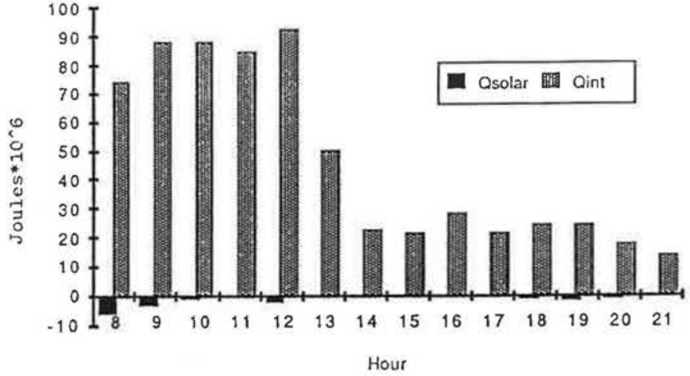
March 1985

Montorfano - Whole Building - March 1985 [JOULES * 10 ^ 6]

Date	Qloss	Qint	Qaux	Qsolar Pass.	Qsolar Coll.	Qsolar Total	Sol %	Int %	Aux %
Sat.16	5688.1	305	4557.8	825.3	0.0	825.3	15%	5%	80%
Sun.17	4465.0	0	3230.2	1080.6	154.2	1234.8	28%	0%	72%
Mon.18	4447.1	305	3444.8	612.0	85.3	697.3	16%	7%	77%
Tue.19	4713.0	305	3436.2	598.1	373.7	971.8	21%	6%	73%
Wed.20	4456.7	305	3369.1	590.6	192.0	782.6	18%	7%	76%
Thu.21	5632.3	305	4380.3	947.0	0.0	947.0	17%	5%	78%
Fri.22	5035.4	305	4167.1	469.5	93.8	563.3	11%	6%	83%
Sat.23	3871.8	305	2873.6	538.1	155.1	693.2	18%	8%	74%
Sun.24	3362.1	0	2804.5	445.5	112.1	557.6	17%	0%	83%
Mon.25	3424.3	305	2466.6	424.7	228.0	652.7	19%	9%	72%
TOT.	45095.8	2440	34730.2	6531.4	1394.2	7925.6	18%	5%	77%

TABLE 8

Collector heat balance 16 March



Montorfano - March 16, 1985

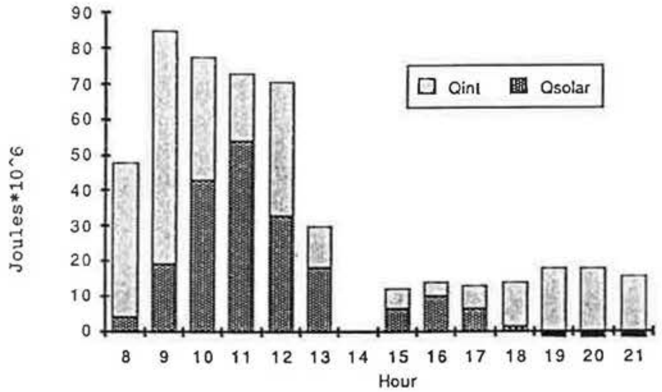
Solar Collector Heat Balance

[JOULES * 10^6]

date	h	T.ext.	FAN MINUTES ON TIME 1	2	3	Insol.	Qsol	%	Qimm. Total	Q Integr.
16 -	1	2.1								
16 -	2	1.8								
16 -	3	1.4								
16 -	4	1.5								
16 -	5	1.2								
16 -	6	0.2								
16 -	7	-0.1								
16 -	8	0.4	49	49	49	1.05	-6.4		68.3	74.7
16 -	9	0.1	60	60	60	2.74	-3.6		84.9	88.4
16 -	10	-0.4	60	60	60	3.78	-1.4		86.9	88.4
16 -	11	0.1	60	60	60	3.78	-0.4		84.9	85.2
16 -	12	-0.2	60	60	60	3.93	-2.5		90.3	92.8
16 -	13	0.3	59	25	25	3.78	0.2		50.6	50.4
16 -	14	0.8	50			3.12	-0.6		22.4	23.0
16 -	15	0.2	46			3.44	-0.3		21.3	21.5
16 -	16	0.3	60			4.17	-0.7		27.6	28.3
16 -	17	0.8	48			5.00	-0.2		21.5	21.7
16 -	18	0.7	52			1.56	-1.1		23.4	24.5
16 -	19	-0.1	49			0	-1.7		23.0	24.7
16 -	20	0.6	36			0	-1.5		16.3	17.8
16 -	21	0.8	30			0	-0.4		13.4	13.8
16 -	22	0.6								
16 -	23	0.4	719	314	314	36.35	-20.5		481.5	492.0
16 -	24	0.6								

TABLE 9

Collector heat balance 20 March



Montorfano - March 20, 1985

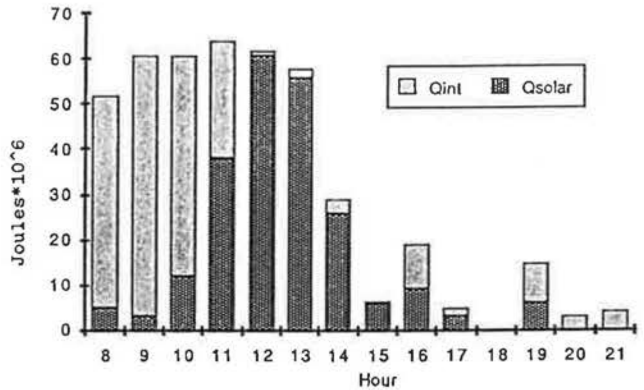
Solar Collector Heat Balance

[JOULES * 10ˆ6]

date	h	T.ext.	FAN MINUTES ON TIME 1	2	3	Insol.	Qsol	%	Qimm. Total	Q Integr.
20 -	1	1.1								
20 -	2	0.5								
20 -	3	-0.4								
20 -	4	-1								
20 -	5	-1.5								
20 -	6	-1.4								
20 -	7	-1.8								
20 -	8	-0.9	33	33	33	18.67	3.9	20.9%	47.8	43.9
20 -	9	3.2	60	60	60	29.27	19.2	65.7%	84.9	65.6
20 -	10	7.1	60	60	60	67.38	42.6	63.2%	77.3	34.7
20 -	11	8.6	60	60	60	74.58	53.5	71.7%	72.3	18.8
20 -	12	8.8	59	59	59	47.28	32.5	68.6%	70.7	38.3
20 -	13	7.6	27	27	27	40.4	17.7	43.7%	30.1	12.4
20 -	14	8.3				25.64	0.0	0.0%	0.0	0.0
20 -	15	7.7	43			21.71	5.9	27.3%	12.3	6.3
20 -	16	7.8	49			36.78	9.8	26.5%	13.6	3.9
20 -	17	7.8	47			13.82	5.8	41.8%	12.6	6.8
20 -	18	6.5	49			2.82	1.2	42.7%	14.6	13.4
20 -	19	5.6	52				-0.9		16.9	17.8
20 -	20	5.2	52				-1.4		16.9	18.3
20 -	21	5.2	46				-0.8		15.4	16.2
20 -	22	5								
20 -	23	3.9	637	299	299	378.35	192.0	42.9%	485.3	293.3
20 -	24	3.5								

TABLE 10

Collector heat balance 25 March



Montorfano - March 25, 1985

Solar Collector Heat Balance

[JOULES * 10ˆ6]

date	h	T.ext.	FAN MINUTES ON TIME 1	2	3	Insol.	Qsol	%	Qimm. Total	Q Integr.
25 -	1	2.9								
25 -	2	2.9								
25 -	3	2.3								
25 -	4	2.8								
25 -	5	3.7								
25 -	6	3.5								
25 -	7	3.4								
25 -	8	5.1	48	48	48	18.37	4.7	25.5%	51.5	46.8
25 -	9	6.6	58	58	58	16.64	3.2	19.4%	61.0	57.8
25 -	10	9.4	60	60	60	45.57	12.1	26.6%	61.5	49.3
25 -	11	11.9	60	60	60	76.02	37.6	49.5%	64.0	26.4
25 -	12	13.5	60	60	60	105.77	60.6	57.3%	61.9	1.3
25 -	13	14.5	55	55	55	98.67	56.0	56.8%	58.3	2.3
25 -	14	13.1	35	35	35	40.04	26.3	65.7%	29.8	3.4
25 -	15	12.4	5	15	5	37.28	5.6	15.0%	5.7	0.1
25 -	16	13.9		56		65.33	8.5	13.1%	18.4	9.9
25 -	17	13.1		18		42.63	2.6	6.0%	4.6	2.1
25 -	18	11.5				13.9	0.0	0.0%	0.0	0.0
25 -	19	10.2		58		17.2	5.6	32.3%	14.3	8.7
25 -	20	8.9	10	3		0	0.0		3.0	3.0
25 -	21	9.1	18			0	0.0		4.3	4.3
25 -	22	8.4								
25 -	23	8	409	526	381	577.42	228.0	39.5%	438.2	210.3
25 -	24	6.8								

Another obvious modification will be to utilize the air heated by the solar collector in the afternoons. However, not in the existing mode of operation, namely, to enhance the ventilation rates, but to circulate the air through the building and the collector. This can store the solar energy in the thermal mass of the building for later use.

In conclusion the solar contribution of 18% (15% passive, 3% active) to the total building load is good. With slight modifications of the operating system this could be improved to 20 or 25%. It is pointed out that the data presented here are for an exceptionally cold winter season and for a short period (only 10 days). For longer periods and normal winter conditions, 25% or higher fractions of the total load can be met by solar contributions.

Unfortunately no detailed previous energy bills are available. Thus it is not possible to discuss the expected savings. One of the recommendations to the school administration is to keep detailed energy billing data for other schools in the Lombardy Region.

The preliminary analysis presented here indicates that it is possible to assess the effects of retrofit measured on energy savings using measured values of temperatures, auxiliary energy and weather variables. In this paper only the retrofitted solar air heater performance is assessed.

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