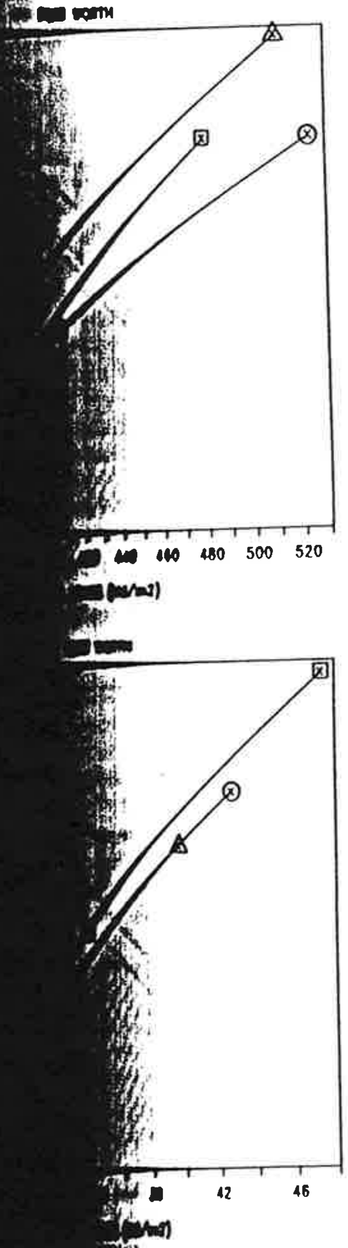
#6605



oll loads: Fort Worth.

#6605

EVALUATION OF RESIDENTIAL BUILDINGS SPACE HEATING ENERGY DEMAND : COMPARISON OF SIMPLIFIED METHODS

C.Aghemo, L. Bongiovanni and M. Filippi
Dipartimento di Energetica, Politecnico di Torino
C.so Duca degli Abruzzi 24,10129-Torino, ITALY

G.V. Fracastoro
Istituto di Fisica, Facolta' di Ingegneria, Universita' della Basilicata
Via N. Sauro 85,85100-Potenza, ITALY

1. Introduction

In order to carry into effect an energy savings policy it is important that standard methods for determining space heating energy demand are available. With the aid of this design tool it would be possible to calculate, at the design stage, the energy savings with different technologies. Still more important in the short period will be the check of the fuel consumption of an existing building, whether to estabilish the energy convenience and service economy, or to provide a reference for the correct use of the building installation system, or to plan a retrofit on an existing building-installation system.

These design tools should be fast and easy to use also to people with no specific knowledge, they should require few and easy to find input data, and be available as computer codes.

2. Description of program BILTE

BILTE is a computer program designed to evaluate the design heat losses and to estimate the seasonal energy and fuel consumption of a building. It may be run on small personal computers, and requires a limited number of input data.

BILTE has been specially developed to assess the energy performance of the building stock owned by the municipality of Torino (about 300 buildings, mainly schools and offices); the input data may be collected in situ, or deduced from the design of the building, according to a specific format requiring information about :

i) the building as a whole (volume, number of air changes, boiler efficiency, etc.)

ii) the different parts of the building envelope (surfaces surrounding the heated volume and cold bridges).

BILTE belongs to the family of the so-called "simplified models", which make use of the "free heat utilization coefficient" to take into account the most important dynamic factors affecting the energy demand of a building. It is particularly suitable for monthly calculations, and may be used for buildings of whatever complexity, provided they are considered thermally homogeneous(i.e., isothermal).

The calculation scheme is the standard one for this category of models, in which the classical energy balance

$$G*Hi*n = Ew(Ti) + Ev(Ti) - (Er + Ef + Ei) \tag{1}$$

is substituted by the following expression making use of the utilization coefficient:

$$G*Hi*n = Ew(Tir) + Ev(Tir) - Cu*(Er + Ef + Ei) \tag{2}$$

where

G = fuel consumption during time t
Hi = lower heating value of the fuel
n = average efficiency of boiler and distribution system
Ew(Ti),Ew(Tir) = energy losses across the building envelope, referred to indoor temperature Ti or Tir
Ev(Ti),Ev(Tir) = energy losses for infiltration and ventilation, referred to indoor temperature Ti or Tir
Cu = utilization coefficient
Er = energy contribution due to solar radiation absorbed by opaque walls
Ef = energy contribution due to solar radiation entering across the glazed surfaces
Ei = energy contribution of internal heat sources

There is no need to discuss in detail each therm of the two equations above; however the following features, specific of BILTE, should be emphasized :

- the temperature difference between heated and non heated spaces has been assumed to be a constant fraction of the indoor-outdoor temperature difference;
- in order to take into account the variations of the inside surface coefficient with respect to its standard value, due to the influence of the number of cold surfaces on the infrared radiative exchanges, a reduction coefficient fc /1/ has been introduced in the calculation of trasmission heat losses;
- the effect of intermittent heating has been evaluated in terms of a reduced indoor temperature, using a lumped parameters model of the building;
- the free heat utilization coefficient, derived from /2/, is a function of the "free heat-losses" ratio and of the "mass-free heat" ratio.
- the seasonal efficiency of the boiler, derived from /3/, is given by:

$$ng = (1 - Pcn - (1-x)*Pdn)/(1 + x*Pdn/(m*nn)) \tag{3}$$

where

Pcn = nominal (full-load) chimney losses
Pdn = nominal jacket losses
x = wet jacket ratio
m = load factor
nn = nominal efficiency

3. The reference model

The model chosen to validate BILTE is based on a well known simplified method described on the Règles Th-B 85 of the French CSTB (Centre Scientifique et Technique du Batiment) /4/. In fact, the CSTB model (named THB85) is fully comparable with BILTE: it is a static model of the same level of complexity as BILTE and considers the whole building isothermal.

Looking at table 1, the use of the free heat utilization coefficient is immediately recognizable in both methods. There are, however, a number of differences which should be noticed:

- The time basis of BILTE may vary from one month upwards, while THB85's time basis is fixed and equal to the heating period.
- BILTE makes use of a more datailed evaluation of the internal loads.
- BILTE takes into account the effect of the internal radiative exchanges by means of the fc factor, while THB85 does not.
- The functional dependences of the utilization coefficient are different in the two methods.
- BILTE allows the prediction of fuel consumption introducing the performance of the heating plant, while THB85 does not.
- BILTE considers the case of intermittent heating, while THB85 does not
- THB85 makes use of a detailed procedure to evaluate the shading coefficient, while BILTE does not.

Table 1. Comparison of input data

BILTE method	THB85 method
building data	
- net heated volume	- net heated volume
- area and transmittance of external surfaces	- area and transmittance of external surfaces
- heat loss coefficient and legtnh of cold bridges	- heat loss coefficient and length of cold bridges
- forfeit value of the building mass	- specific mass of walls
- shading coefficient of glazed walls	- total hemispherical absorbtion factor of external surfaces
- average thermal trasmittance	- solar factor of glazed walls
- number of lodgings in the building	- shading coefficient for opaque and glazed walls
- expected number of inhabitants in the building	- self shading coefficient of opaque and glazed surfaces
environment data	
- average monthly outdooor temperature	- average outdoor temperature
- indoor air temperature	- indoor air temperature
- average daily solar radiation for the orientation of the vertical and horizontal surfaces	- average seasonal solar radiation on south facing vertical surfaces (heating period)
- number of air changes per hour	- number of air changes per hour
- conventional length of heating period	- conventional length of heating period

4. Parametric analysis

The two models previously described have beeen used to perform a parametric analysis of the energy demand as a function of building typology, orientation, thermal capacity, and percent glazed surface. In order to make the parametric analysis more realistic, three real buildings whose design was detailedly known were chosen as the basis of the comparision :

i) "Isolated Building" (IB), i.e., a small three-floors, six-flats building;
ii) "Row Building" (RB), with three floors and 30 flats;
iii) "Large Building" (LB), eight floors and 96 flats;

As a starting point, the buildings were taken exactly as they are: the IB is not insulated, while RB and LB are insulated, since they were built after the Law on building insulation came in force (1976).

The following parameters have been modified with respect to the original values:

1- glazed surfaces
  1 original,
  2 +25% on main facade and +15% on the lateral facades,
  3 +40% on main facade and +25% on the lateral facades;
2- orientation
  1 main facade oriented towards South,
  2 main facade oriented towards West,
  3 main facade oriented towards North;
3- thermal capacity
  1 150 kg/m2 floor - corresponding to French "weak thermal capacity",
  2 350 kg/m2 - corresponding to "medium thermal capacity",
  3 500 kg/m2 - corresponding to "high thermal capacity".

The following fixed hypotheses were adopted in BILTE program:

- shading factor equal to 0.7 on all surfaces;
- internal gains equal to 250 W/flat plus 83 W/person;
- number of air changes per hour equal to 0.5.

As for THB85 fixed hypoteses were :

- no shading from adjacent building, but only from the building itself;
- "tilt" factor for solar radiation as calculated in /5/;
- number of air changes per hour equal to 0.5.

Eighty-one cases were analysed, that is, 27 cases for each typology. Each one is marked with a numerical code made of three digit: the first one refers to the chosen amount of glazing, the second to the orientation, the third to the thermal capacity.

The following results were considered in the comparison:

i) solar heat gains on glazed and opaque surfaces
ii) trasmission heat losses
iii) free heat utilization coefficient
iv) energy demand.

The results of the comparison, expressed in terms of percent difference between THB85 and BILTE, are reported in Fig. 1 to 4.

i) Solar heat gains ("gross" value)

Fig. 1 shows that the difference between BILTE and THB85 ranges between -43% to +19%; the difference is higly dependent on building typology, dependent on the insulation level (due to the different transmissivity of double glazing), slightly dependent on orientation, almost insensitive to glazing surfaces, and insensitive to thermal capacity.

ii)Trasmission heat losses

Tab. 2 shows that BILTE trasmission heat losses are always smaller (0% to 10%) than THB85's, and increasing with building lossiness.

Table 2. Comparision of trasmission heat losses

Building	Fenestration	(THB85 - BILTE)/THB85
Isulated Building	1	+ 8.5 %
	2	+ 9.1 %
	3	+ 9.5 %
Row Building	1	- 0.1 %
	2	+ 0.6 %
	3	+ 1.0 %
Large Building	1	+ 7.7 %
	2	+ 7.8 %
	3	+ 7.9 %

iii) Free heat utilization coefficient

Fig. 2 shows that the difference between BILTE and THB85 ranges between -2% to +%; the difference is more sensitive to thermal mass, less sensitive to orientation and glazing surfaces, almost insensitive to building typology. Fig. 3 shows that the range of BILTE free heat utilization coefficient is larger than THB85's. However, these differences have a minor influence on the energy demand of the building.

iv) Energy demand

Fig. 4 shows that THB85 always predicts higher energy demand than BILTE. The difference ranges between 13% and 24%. Due to the dependence on the free heat utilization coefficient, these differences are smaller when the thermal mass is low and larger when the thermal mass is high. The difference is slightly sensitive to orientation and almost insensitive to fenestration.

5. Comparison with experimental results

BILTE and the reference program have been compared not only on the basis of their general features, and of the parametric analysis, but also on the grounds of data collected on a number of real buildings. Of these buildings, only one was completely instrumented; data on the others consisted of geometric and thermophysical features obtained by auditors, while the energy consumption was derived from the fuel bills provided by the occupants. Therefore, the two experimental comparisons should be kept separate.

The instrumented building is the same isolated building (IB) which was used for the parametric analysis, situated on the ills around Torino;

its geometrical and thermophysical features were well known (V = 2196 m3, specific volume losses 0.953 W/m3.K). The following quantities have been continuously monitored for 151 days:
- air temperature and relative humidity in three sample rooms;
- outdoor temperature;
- solar radiation on the horizontal plane;
- useful power provided by the boiler to feed water;
- fuel flow rate.

Data on electric energy consumption and gas for cooking were also measured on a weekly basis.

The comparison has been performed introducing in the model the actual meteorological data (air temperature and solar radiation), while all the parameters dealing with the occupants' behaviour have been given standard values (indoor air temperature, internal gains, shading coefficient, etc.). The comparison has been made using the energy demand of the building (i.e., the useful heat provided by the plant), instead of the fuel consumption, since model THB85 does not include the calculation of seasonal boiler efficiency. The results of the comparison are reported in Table 3.

Table 3. Measured and calculated monthly energy demand, kWh.

MONTH	Days	DD	Measured	BILTE	Diff.%	THB85	Diff.%
November	15	225	8673	7662	- 12	9561	+ 10
December	31	552	17479	19949	+ 14	23851	+ 10
January	31	546	18394	19929	+ 8	23559	+ 28
February	28	510	17789	18043	+ 1	21290	+ 20
March	31	425	12452	13219	+ 6	17746	+ 43
April	15	159	5063	4245	- 16	6573	+ 30

BILTE shows a fair agreement with the experimental results, while the reference program shows a systematic overestimate. It may be interesting to observe that the "trend" of the differences between measured and calculated values is very much the same, indicating that, apart from the systematic overestimate of THB85 (which may be attribuited to the overestimate of trasmission heat losses as well as to the underestimate of internal gains), both models show some variable error, maybe depending on the actual variation of the number of air changes (considered constant by both models).

The second type of comparison made use of some of the data collected during a large scale survey on 369 buildings (mainly schools and office buildings) belonging to the Municipality of Torino. They were collected according to a format specified by the authors, consistently with the input required by BILTE, but the data collection was not undertaken by the authors. For 22 gas heated buildings the data included fuel consumption, and they could therefore be used for this comparison.

The results of the comparison are presented in Tab. 4. It does not include the results of THB85 model, as some of its input data were not available.

The agreement between experimental and theoretical data is not entirely satisfactory; however, it should be clearly stated that, in this case, the calculated values were affected by the errors made at each step of the whole procedure, that is, the errors implicit in a large scale survey, in the digitation of data, and in the model itself.

In 5 cases (23%) the differences between calculated and measured data was smaller than 10%, in 12 cases (55%) it was smaller than 20%, in 16 cases (73%) it was smaller than 30%. In the remaining 6 cases, the large discrepancies seem to be due to the accuracy of the survey rather than to the model's: for istance, the 5 air changes per hour declared by the surveyers in some cases seem rather too high for buildings not provided with mechanical ventilation.

Table 4. Comparison between measured and predicted gas consumtion.

Building No.	Measured gas volume (m3)	Calculated gas volume (m3)	Difference (C-M) %
1	23626	37066	+ 57
2	90628	105390	+ 16
3	506820	1055571	+ 108
4	489089	1159539	+ 137
5	98131	107132	+ 9
6	657076	805815	+ 23
7	16094	13994	- 13
8	75167	92328	+ 23
9	7258	8382	+ 16
10	110297	116333	+ 6
11	8439	7821	- 7
12	10512	8639	- 18
13	27978	32636	+ 17
14	84113	58790	- 30
15	10315	8850	- 14
16	10173	6760	- 34
17	40980	30074	- 27
18	87313	83332	- 5
19	6720	7789	+ 16
20	87233	64921	- 26
21	2515	7323	+ 191
22	31200	29087	- 7

6. Conclusion

The following main comments may be made about the calculation results;
- the tested methods show systematical differences in the evaluation of the energy balance components. However,in the parametric analysis the minimum amd maximum values for each building are reached in the same conditions of orientation, thermal mass and fenestration;
- in the evaluation of the energy consumption of a building these simplified methods can not reach a precision higher than 10 - 15% , but they are useful to evaluate the relative differences for energy consumptions caused by various technologies applied to the same building or by various shapes, orientations, fenestration, ect.;
- when the building is a solar building and solar energy contributions are about equivalent to thermal losses the simplified methods may lead to unacceptable errors.

7.References

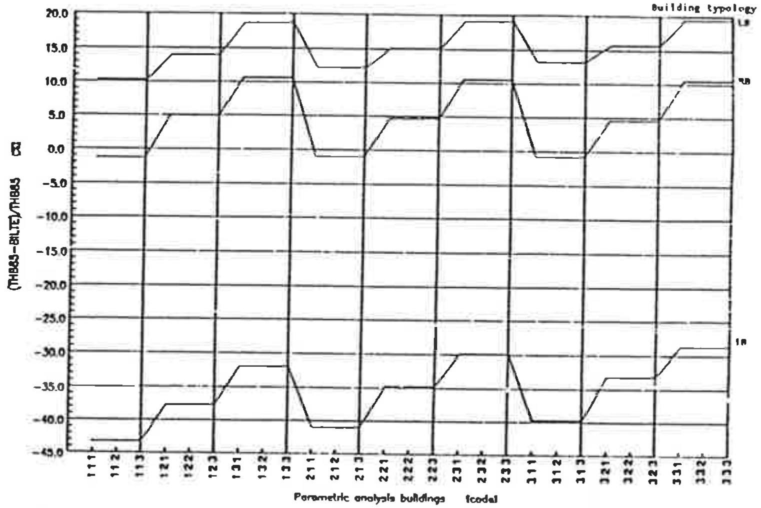
/1/ L.Agnoletto, P.Brunello, R.Zecchin "Simple methods for predicting thermal behavior and energy consumption in buildings", A.S.H.R.A.E. DOE Conference, Florida, 1979.

/2/ D.M. Sander, S.A. Barakat "Mass and Glass", A.S.H.R.A.E. Journal, november 1984.

/3/ P.Anglesio, G.V.Fracastoro "Valutazione del rendimento medio stagionale di sistemi caldaia-bruciatore per riscaldamemto di edifici", Atti del V Seminario Informativo PFE-RERE, PEG, Milano, 1982.

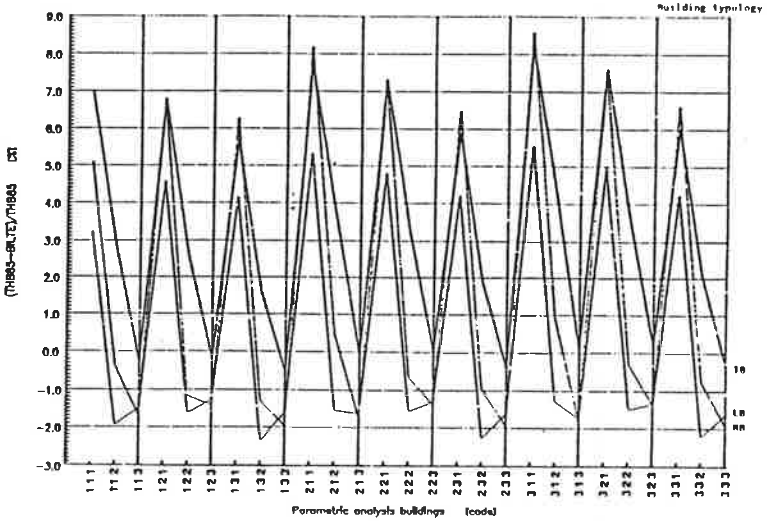
/4/ Regles Th-B 85 "Calcul du coefficient volumique de besoin de chauffage des logementes", C.S.T.B. Cahier 2001, Livraison 259, 1985.

/5/ C.Aghemo, M.Filippi, G.V.Fracastoro "Valutazione del fabbisogno energetico per riscaldamento ambientale di un edificio residenziale: metodi semplificati a confronto", Congresso A.T.I., Trieste, 1985.



SOLAR HEAT GAINS ON GLAZED AND OPAQUE SURFACES

Fig. 1. Solar heat gain - Difference between BILTE and THB85.



FREE HEAT UTILIZATION COEFFICIENT

Fig. 2. Free heat utilization coefficient - Difference between BILTE and THB85.