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RICERCA SISTEMA ELETTRICO

Potenzialità e limiti applicativi dei modelli statistici e predittivi inversi per lo studio dei usi energetici totali negli edifici (IEA – ECBCS Annex 53)

M. Filippi, S. P. Corgnati, V. Fabi, N. Talà

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Responsabile del Progetto: Gaetano Fasano, ENEA

Indice

Sommario

L'attività condotta dal gruppo di ricerca TEBE (www.polito.it/tebe) del Dipartimento Energia del Politecnico di Torino si è sviluppata all'interno dellelinee di approfondimento dettate dal progetto ECBCS-Annex 53 "Total Energy Use in Buildings" della International Energy Agency, iniziato con le riunioni preliminari nel 2009 e termine nel 2012. Il gruppo TEBE ha partecipato in modo propositivo fin da subito allo sviluppo del progetto stesso, facendosi carico del coordinamento di uno dei Sub-Task.
In generale, lo scopo del progetto IEA-ECBCS Annex 53è l'approfondimento dei metodi di previsione dei consumi totali e degli usi finali di energia negli edifici, sia con modelli predittivi diretti che indiretti, al fine di identificare e valutare l'efficacia di misure, tecniche e politiche di risparmio energetico applicate a diverse scale di studio, dalla scala del singolo edificio fino a quella grande campione edilizio. A questo si affianca la raccolta e l'analisi critica di esperienze significative per una migliore comprensione del comportamento energetico reale degli edifici.I noltre, uno specifico approfondimento è dedicato allo studio del comportamento dell'utente e alla determinazione che esso ha sui consumi energetici reali degli edifici.

Introduzione

L'Annex 53 si propone di raggiungereuna migliore comprensione dei dati di consumo energetico reale dei sistemi "edificio-impianti", per la valutazione e lo sviluppo di nuove tecnologie e azioni di risparmio energetico. Rilevante diviene dunque la conoscenza dei principali fattori che influenzano il consumo totale di energia negli edifici e le loro specifiche/reciproche interazioni. Uno degli obiettivi chiave del progetto risulta dunque essere lo studio delle cause principali influenzanti il consumoenergetico,tenendo conto dei fattori attribuibili sia alle prestazioni del sistema edificio-impianto sia al comportamento dell'utente, al fine di prevederne per entrambi gli effetti in edifici nuovi e ristrutturati, nonché il rapporto costi-benefici delle relative misure di risparmio.
Obiettivo ultimo, infine, diviene lo studio di tecniche per la standardizzazione e il benchmarking del consumo totale di energia negli edificio al fine di creare indici sintetici che considerino anche i fattori legati all'utente: ciò dovrebbe consentire anche una più facile comprensione dei sistemi di energy labelingd a parte dell'utente stesso, favorendo l'informazione sui comportamenti scorretti.
Per raggiungere gli obiettivi sopra illustrati, l´Annex 53 si divide in 4 Subtask:

- Subtask A: Definition and Reporting
- Subtask B: Case Studies and Data Collection
- Subtask C: Statistical Analysis
- Subtask D: Energy Performance Evaluation.

Attività del Gruppo Tebe del Dipartimento Energia, Politecnico di Torino

Il Gruppo di Ricerca Tebe del Dipartimento Energia del Politecnico di Torino partecipa all'Annex 53 nelle attività dei Subtask A, Subtask B e Subtask C. Di questo ultimo Subtask il Gruppo di Ricerca è anche coordinatore.
Particolarmente attiva è stata inoltre la partecipazione alla Task-Force su "Occupant Behavior" specificamente ideata durante lo sviluppo del progetto.
L'apporto nel Subtask A ha riguardato la definizione degli indici normalizzati per la caratterizzazione delle prestazioni energetiche dell'edificio e delle caratteristiche del Database di riferimento rispetto a cui i differenti database impiegati nel progetto dovranno confrontarsi.
L'apporto nel Subtask B riguarda l'analisi di un caso studio, un edificio per uffici di piccole dimensioni nel quale è condotto un monitoraggio continuo di tipo energetico-ambientale. Gli approfondimenti sono indirizzati alla sperimentazione di tecniche monitoraggio energetico e ambientale wireless, non invasive, applicati ad un edificio storico.
L'attività nel Subtask C riguarda l´analisi di potenzialità e limiti degli strumenti statistici per una migliore descrizione degli usi finali dell´edificio e di metodi di calcolo inversi per una piú robusta previsione dei consumi energetici futuri. Inoltre, cruciale diviene l´analisi dei fattori che influenzano l´uso finale di energia negli edifici, e, tra questi, il comportamento dell´utente (Task Force).
Si riporta di seguito un estratto del documento descritto del ST-C del progetto Annex 53, nel quale si illustra la struttura del Sub-Task coordinato.

"The structure of ST-C is shown in the following figure 1.

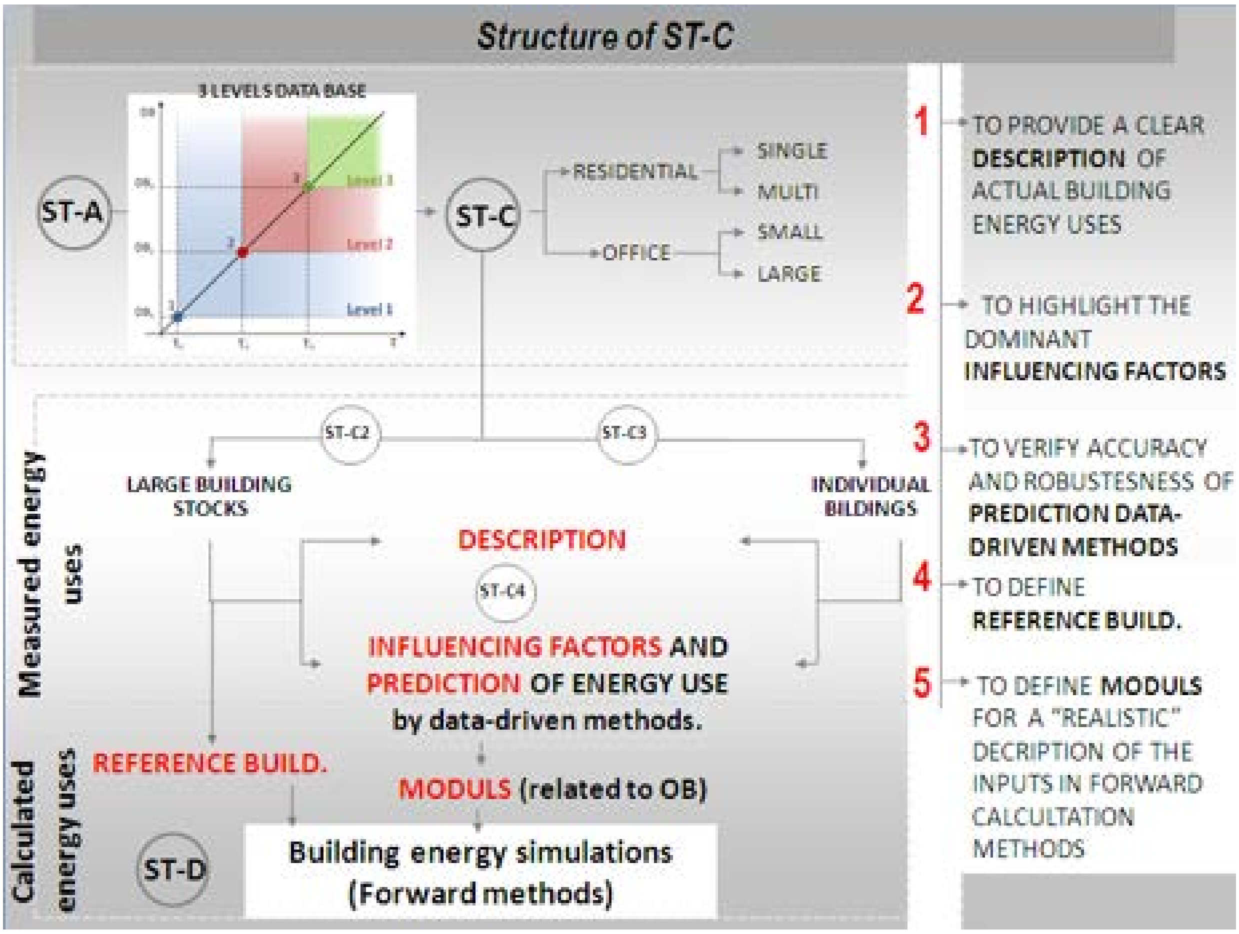

Figure 1 - Research structure of ST-C

Looking at the upper left of the figure, the deep connection between ST-A and ST-C is evident: in order to developed statistical analyses a structured database has to be available and quantities/indexes with their terminology has to be clearly defined .

The proposal about the definition of a 3 level database has been shared with ST-A, after the discussion on the results of a dedicated carried out literature reviewing activity (this topic has been one of the key issue of ST-C, see "Attività A.1" in the following section).

The 3 level database structure refers both to the frequency of energy consumption (annual, monthly, daily/hourly) and to the categories of considered influencing factors. To apply statistical tools and data-driven methods, the availability of a clearly structured database, with a well defined format and item definition, is fundamental: unfortunately, the importance of this matter is too often underestimated.

- *both for large building stocks (up to analyses at regional/national level) and for individual buildings, statistical tools can be mainly used to:*
- *statistically describe the characteristics of object of the study*
- *point out the dominant factors influencing energy consumptions*
- *predict future total energy uses.*

When statistical analyses are used to predict, the performed literature review showed that large building stocks are the main subject of the investigation and the studies are mainly performed applying regression methods or neural network methods."

Descrizione delle attività svolte, risultati, discussione e pubblicazioni

Si elencano di seguito le attività previste e condotte dal gruppo di ricerca.

Attività A

Potenzialità e limiti applicativi dei modelli statistici e predittivi inversi

Finalità

Raccolta, esame e armonizzazione delle esperienze presenti nella letteratura internazionali riguardanti l'uso di metodi statistici e di modelli predittivi per la stima dei consumi energetici degli edifici, con particolare riferimento sulle esperienze condotte dai partner del progetto Annex 53.

Azione condotta

L'analisi bibliografica relativa ai modelli statisticiè stata condotta sulla base di quattro punti cardine: soggetto del modello, obiettivo del modello, struttura del dataset impiegato ed infine modello adottato.

Il soggetto del modello rappresenta la dimensione del problema in esame che può riguardare il singolo edificio quanto un patrimonio di edifici.

La messa a fuoco dell'obiettivo del modello consente una classificazione per effetto degli scopi che il modello intende raggiungere e che possono essere sintetizzati in: modelli finalizzati alla previsione, alla diagnosi, alla stima degli 'energy savings', all'identificazione di benchmark, al controllo ecc..

Lo studio della struttura del dataset è stato impostato considerando la variabilità dei dati in termini temporali e di categorie di fattori influenzanti.

Infine la ricerca ha evidenziato le metodologie adottate (variable-base degree-day model, linear regression model, change point model, calibrated simulation, artificial neural networks model, engineering method, statistica lmethod, data mining method, ecc..) in relazione al soggetto, all'obiettivo e al database utilizzato.

A 2 – Report potenzialità e limiti applicativi dei modelli statistici e predittivi

Sulla base delle ricerche condotte dal gruppo di ricerca TEBE e più in generale dai partner del progetto Annex 53, esame critico delle potenzialità e dei limiti applicativi del modelli statistici e predittivi inversi per la stima dei consumi energetici degli edifici, con particolare riferimento sulle esperienze condotte dai partner del progetto Annex 53.

Azione condotta

Sono state raccolte le diverse esperienze dei partner del progetto attraverso format comuni. In particolare, gli studi condotti dai partner sono stati richiesti sulla base di due specifici format: uno per la raccolta di contributi "sintetici" di massimo 2 pagine, e uno,successivo, per la raccolta dei contributi "estesi", di massimo 10 pagine. Il contributo "esteso" contiene una discussione critica su:

- database e variabili prese in considerazione nelle analisi e elaborazioni dei dati;
- metodo di analisi utilizzato e risultati principali;

- valutazione generale sulle potenzialità del metodo di analisi e campo/i di applicazione appropriato/I (mettendo in luce le ragioni per le quali il metodo è stato usato e se è stato efficace per le indagini).

Parallelamente è stata condotta la stesura del Report Finale, per ora in fase di sviluppo (draft) del ST-C, contenente la descrizione teorica di quanto sviluppato all'interno del Sub-Task e il riepilogo delle esperienze condotte dai partner.

Risultati/Deliverable:

Rapporto tecnico "Potenzialità e limiti applicativi dei modelli statistici e predittivi inversi per lo studio dei usi energetici totali negli edifici"

da: Rapportotecnico "ST C - STATISTICAL ANALYSIS AND PREDICTION METHODS. Interim Report"

da: Rapportotecnico "Synthesis Report of case studies".

RESULTS:

Si riporta di seguito un estratto della analisi bibliografica condotta, evidenziano in particolare la logica attraverso cui le pubblicazioni scientifiche sono state esaminate con particolare riferimento alla struttura del database.

The need to define a reference structure for the database belongs to the results of a literature review focused on international research journals dealing with statistical analyses and inverse modeling approach for prediction of building energy consumptions. The analyzed paper have been organized through a specific format, as following described.

First of all, it is important to remark that the subject on which the analysis will focus has to be clearly defined at the very beginning of the investigation process. Forcing a subdivision in families, the subject of the statistical investigation may be divided in:

- *Individual building, that is an analysis focused on one specific single building (or a group of individual buildings)*
- *Large building stocks, that is an analysis of a group of statistically representative buildings, typically showing similarities in terms of use (residential, office, school, etc)*
- *Regional/national level analyses, that are typically statistical analyses developed on database with large number of buildings on national basis.*

It is better here to remind that the consideration here presented refers to residential (single and multifamily houses) and office (small and large) buildings, according to the goals of Annex 53.

In general, to perform suitable analyses, the number of building and the (minimum) number of information required to describe each building are related, as shown in the diagram of figure 2.

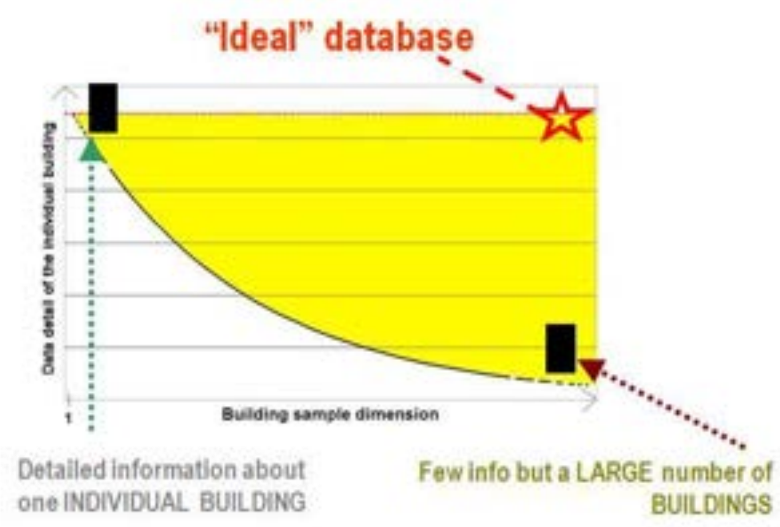

Figure2 – Diagram of databases information according to building sample dimension

When a single individual building is the subject of the investigation, a high number of parameters describing its energy behaviors are required (one building, but with lots of information) and the analysis can be pushed up to each specific energy end use. On the contrary, when analyses are performed at national level, a lot of building but described by few parameters are available (lots of buildings, but with few information).

When the subject of the study is chosen, the database may be identified through two main characteristics:

1. *Categories of influencing factors which are collected, according to six categories previously defined*
2. *Sampling frequency of the time dependent variables (consumptions and parameters belonging to the six categories of influencing factors)*

About the point 1 above, typically the database structure can refer to 3 "level":

Level 1 – categories of influencing factors: climate, envelope, systems

Level 2 – categories of influencing factors: Level 1 + control & maintenance, indoor environmental conditions

Level 3 - categories of influencing factors: Level 2 + occupant behavior

The three levels may also contain information about the seventh factor (social aspects).

About the point 2 above, typically the database structure can collect time dependent variables as follow:

Level 1 – frequency: annual*

Level 2 – frequency: monthly*

Level 3 - frequency: hourly (or sub-hourly)*

As a consequence, the databases used in practice can be classified according to their reference structure and placed within a matrix as shown in table1.

		Categories of influencing factors		
		Level 1	*Level 2*	*Level 3*
		Climate Envelope systems	Level 1 Control&Maintenance Indoor environmental conditions	Level 2 Occupant behaviour
Frequency of the time dependent variables	*Annual*			
	Monthly			
	Hourly (sub-hourly)			

Table 1 – Database structure according to categories of influencing factors and time frequency of dependent variables

The database structure is highly connected to the statistical and predictions methods that can be adopted for the data analyses and elaborations and, consequently, with the foreseen results obtained through the performed investigations.

Database structure and literature review

The database structure previously introduced is used to define a criterion for the classification of the selected and analyzed papers.

In particular, each examined paper is characterized by the following items:

- *authors*
- *title*
- *database typologies (that is to which kind of database reference structure it refers)*
- *adopted method for the data elaboration finalized to energy consumption analysis/predition*
- *subject of the analysis*
- *goal of the analysis.*

These information are synthesized as presented in table 2 where, for the sake of brevity, only few of the more than 50 analyzed paper are shown.

The whole list of the examined paper will be presented in the final report.

Moreover, this work aimed at cataloguing papers is going on and the table is in continuous updating.

Author	Title	Influencing factors ccategories	Adopted method	Subject of the analysis	Goal of the analysis
Merih Aydinalp, V. Ismet Ugursal, Alan S. Fung	Modeling of residential energy consumption at the national level	***3+***	***Engineering method/conditional demand analysis method/artificial neutral network***	Large building stocks/residential	Comparative assessment of the three methods
H. Farahbakhsh V. I. Ugursal, A. S. Fung	A residential end-use energy consumption model for Canada	***2***	***Engineeringmethod (CREEM)***	Large building stocks/residential	Forecast building energyconsumption
Merih Aydinalp-Koksal, V. Ismet Ugursal	Comparison of neural network, conditional demand analysis, and engineering approaches for modeling end-use energy consumption in the residential sector	***3+***	***Conditional demand analysiss method***	Large building stocks/residential	Forecast building energy consumption
MerihAydinalp, V. Ismet Ugursal b, Alan S. Fung	Modeling of the space and domestic hot-water heating energy-consumption in the residential sector using neural networks	***3+***	***Artificial neutral network***	Large building stocks/residential	Forecast building energy consumption
MerihAydinalp, V. IsmetUgursal, Alan S. Fung	Modeling of the appliance, lighting, and space-cooling energy consumptions in the residential sector using neural networks	***3+***	***Artificial neutral network***	Large building stocks/residential	Forecast building energy consumption

Table 2 – Organized structure of the literature review activity

Note: in "Influencing factors categories", the symbol + means that also data referring to "social aspects" are collected.

Moreover, the entire literature review activity, organized through the format of Table 2, is available in electronic format.

ATTIVITA' A.2

Si riporta di seguito un estratto del "Syntheis Report" di Annex 53, relativo alla applicazione dei metodi statistici per l'esame degli usi finali degli edifici. A seguire vengono altresì presentate, a titolo esempio, due schede sintetiche di presentazione dei casi di studio sviluppati.

" The general approach for statistical analyses and prediction methods used in Annex 53 project is here described. The diagram presented in this section shows the general scheme that will be followed in the final report to discuss the topics related to statistical analyses and prediction methods for total energy use in buildings.

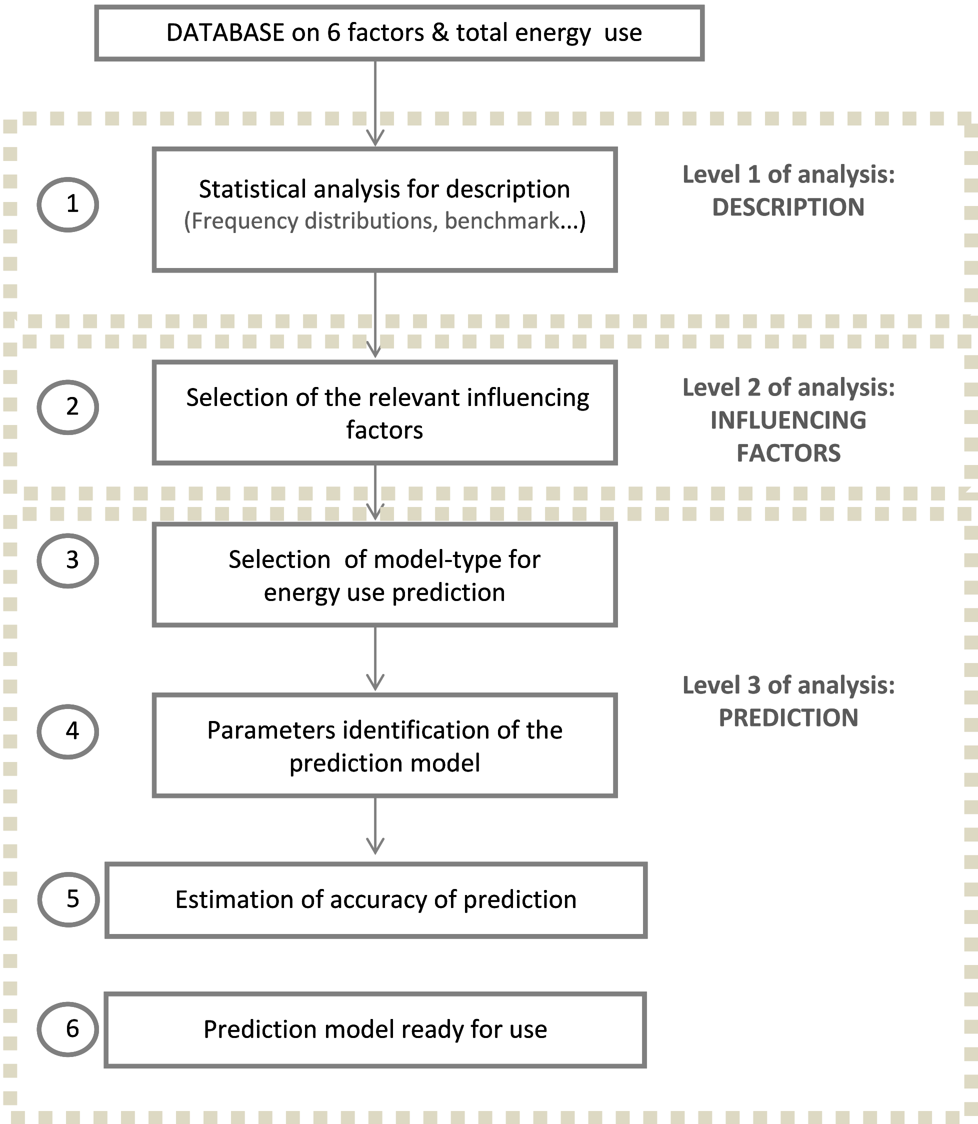

Figure 1 - Flow chart for the general approach for statistical analysis and prediction methods

Thanks to the contributions of the partners participating in ST-C, the Subtask C leader work group performed a reviewing of the developed activities about the assessment of Total Energy Use in Buildings by “inverse (data-driven) methods”. Common questions are faced in the contributions, related to the more appropriate statistical analysis method according to the database level, fixed the goal of the analysis and the dominant influencing factors. This report highlights the relationships among:

- *Subject of the analysis*
- *Goal of the analysis*
- *Structure of the database*
- *Adopted method of analysis*

The ongoing activities in Sub –Task C can be divided, according to sub-task structure, with reference to the subject of the analysis:

- *Large Building Stocks*
- *Individual Buildings*
- *National or Regional level*

Annex 53 partners uniformly faced the two topics, focusing only in one topic or on both, for a total of 9 contributions. In particular, Austria, France, Germany, Norway focused the analysis in individual buildings, while Italy and Japan on both individual buildings and large building stock, and Canada and Spain contributed for large building stock. National or regional analysis issue is faced by Italy (regional database) and by U.S. (national database) as well. As defined in the Annex 53 project, the ST-C partners’ analysis deal with residential or office buildings. In the following table (Table 1) it is delineated the building typologies subject of the analysis through the arrived contributions

	Individual buildings			**Large building stock**		**National-Regional level**	
	Residential	*Office*	*Other*	*Residential*	*Office*	*Residential*	*Office*
TU Wien (Austria)	3 Multi- family houses 8 single-family houses	2 offices					
Concordia University (Canada)				80 houses (single and multi-family)			
CETHIL, INSA de Lion (France)			1 school				
Karlsruhe Institute of Technology (Germany)	1 Multi- family house	1 Multi-storey office					
Polytechnic of Turin (Italy)		1 office building			4000 office buildings	66000 houses (Piedmont regional database)	
Tohoku University (Japan)	6 houses (single and multi-family)			682 houses 80 houses (single and multi-family)	1121 office buildings		
Tohoku University (China houses)				635 houses			
NTNU Trondheim (Norway)		1 office building					
CIMNE (Spain)				9 office buildings			
LBNL (U.S.)							824000 offices (CBECS database)

Table 3 – Distribution by subject of the analysis of the obtained contributions

The goal of the analysis of the arrived contribution can be synthetically divided in:

- *description of subject (statistical characterization of the subject, benchmarking, etc.)*
- *prediction (forecasting) of the energy consumption of the subject.*

Within the individual buildings contributions, a large part is dedicated to the statistical characterization of the subject. The subject description through statistics is delineated with different aims: Norway uses statistical analysis for the identification of driving variables that contributed to energy use, while Austrian and Germany analysis are particularly related to the topic of determining an accurate profile of user behaviour (both in offices and in residential buildings) to represent the energy related behaviour of the occupants. Even if the characterization of the occupant behaviour assumed in the researches different paths, it highlights the increasing importance of the topic.

The theme of prevision (forecasting) of the energy consumption is carried forward by both Japanese and French groups in individual buildings. In particular, the main goal of the French forecasting analysis is heating load as a function of the outdoor temperature, the Japanese analysis in 6 detached houses, the focus was concentrated on the prediction of the energy supply and demand in residential area.

Finally there is a third case, where the first statistical analysis to characterize the subject are used to calibrate the model and forecast the building energy performance. Italy focuses on the determination of total heat loss coefficient and the influence of solar and internal heat gains through a statistical characterization of the building and then calibrates the numerical model by comparing both expected energy need and the real measured consumption, and the expected and real aggregated parameters springing up from the first analysis.

Characterization of the sample is the most common aim within the analysis of a large building stock. In particular, work groups (Italy, Japan, Spain, Canada) focused the investigations on the understanding of the influential factors which determine the energy consumption, establishing reliable building energy demand models. Benchmarks for electrical energy uses and for total primary energy consumption for the whole building stock is a goal present in some of the investigations like in the Italian case on 4000 bank branches.

Prediction is also dealt with in large building stock, in particular with the aim of establishing building energy predictive models and goodness of fit to reality assessment in the case of Italian bank branches and Canadian investigation on residential buildings.

Due to the huge amount of data existing in a database at a national and regional level, the main goal of the investigations are to define building typologies to estimate energy demand of a building stock and to estimate the amount of energy used for different end uses.

	Description		Prediction	
	Individual Building	*Large building stock*	*Individual Building*	*Large building stock*
TU Wien (Austria)	Energy-related user behaviour			
Concordia University (Canada)				To establish reliable building energy demand predictive models
CETHIL, INSA de Lion (France)			To estimate the HVAC energy consumption	
Karlsruhe Institute of Technology (Germany)	Energy-related user behaviour			
Polytechnic of Turin (Italy)	Identification of the influence of solar and internal heat gains	Identification of energy consumption influential factors	To estimate the building energy performance	To establish reliable building energy demand predictive models
Tohoku University (Japan)		Identification of energy consumption influential factors	To predict the peak energy consumption	
Tohoku University (China houses)		Identification of energy consumption influential factors		
NTNU Trondheim (Norway)	Identification of energy consumption influential factors			
CIMNE (Spain)		To analyze three parameters taken as building performance indicators		
National or regional level				
Polytechnic of Turin (Italy)	to estimate energy demand of a building stock			
LBNL (U.S.)	to estimate the amount of energy used for different end uses			

Table 4 – Distribution by goal of the analysis of the obtained contributions

The topic concerning the structure of the database is absolutely not banal and very often it is faced with less rigor: on the contrary, it is a crucial issue. In this section, the partners' contributions are analyzed according to the level of database they have collected.

The database structure referred firstly to the detail of time disaggregation of the energy consumption and of the time dependent influencing factors:

- *Level 1 – Annual energy consumption*
- *Level 2 – Monthly energy consumption*
- *Level 3 – Daily/hourly energy consumption.*

The acceptable minimum level depends on the goal and on the subject of the analysis, but typically:

- *For analyses on large building stocks, level 1 resulted acceptable for the investigations*
- *For analyses on individual buildings, level 2 is considered as the minimum level.*

When the study focuses on very large building stocks, useful analyses can be performed even if few information for each single building is available (annual energy consumption and some influencing parameters) but for a wide number of buildings; when the study focuses on individual buildings, the number of required information increases, at least because the data about energy consumptions (and the corresponding influencing factors !) have to be collected at monthly level.

In particular, in cases where the main aim of the investigations is related to the building occupants, the database contains:

- *Building geometries and qualities*
- *Climate (indoor and outdoor) information*
- *Occupancies and lifestyles.*

Such database characteristics are summarized in table 3 for the arrived contributions.

	Residential		Office	
	Individual Building	*Large building stock*	*Individual Building*	*Large building stock*
TU Wien (Austria)	Level 3		Level 3	
Concordia University (Canada)		Level 3		
CETHIL, INSA de Lion (France)	Level 3			
Karlsruhe Institute of Technology (Germany)	Level 3			
Polytechnic of Turin (Italy)			Level 3	Level 1
Tohoku University (Japan)	Level 3	Level 1		
Tohoku University (China)		Level 1		
NTNU Trondheim (Norway)			Level 3	
CIMNE (Spain)				Level 1
National or regional level				
Polytechnic of Turin (Italy)	Level 1			
LBNL (U.S.)			Level 1	

Table 5 – Distribution by database level of the obtained contributions

The adopted analysis methods in the contributions depends on the goal and the subject of investigations.

Generally, the description of the subject is dealt with regression techniques.

In the contributions on individual buildings, different types of regression analysis (linear, multivariate, logistic, partial least square, based on q-q plot) are used. Norway used partial least square regression to establish a variables mostly contributing energy use in buildings, Austria and German investigations applied multivariate and logistic regression type to identify series of user profiles. Italian investigation with linear regression or French analysis basing the regression on a quantile – quantile plot are aimed to determine correlations between heating energy need and external temperature.

Within large building stock, the identification of possible influential factors on energy consumption is mainly dealt with regression techniques. Quantification method 1 is also used to analyze qualitative factors by Japanese investigations on both residential and office buildings.

	Residential	Office
TU Wien (Austria)	Regression analysis	Regression analysis
Karlsruhe Institute of technology (Germany)	Multivariate linear and logistic regression analysis Model optimization through AIC and Nagelkerke's R^2	Graphical analysis
Polytechnic of Turin (Italy)		Linear regression
Tohoku University (Japan)	Quantification method 1	Multiple regression
Tohoku University (China houses)	Quantification method 1	
NTNU Trondheim (Norway)		Partial least squares regression
CIMNE (Spain)		Linear regression
National or regional level		
Polytechnic of Turin (Italy)	Hierarchical clustering techniques	
LBNL (U.S.)		Regressions techniques

Table 6 – Analysis methods used in the contributions for description of the subject

Prediction methods within the arrived contributions are dealt with both multiple regression analysis and cluster analysis and tree structure.

Multiple regression analysis was chosen to identify a mathematical model able to forecast energy consumption in buildings with a set of already-known individual variables by using linear functions, while the method of neural network (a basic data mining technique) is used to analyze the non-linear relationship between energy consumption and individual variables. Decision tree structure is a data mining techniques using both numerical and categorical variables with interpretable flow-chart tree structures that enables users to quickly extract useful information.

	Residential	Office	Other
Concordia University (Canada)	Tree method technique Cluster analysis		
CETHIL, INSA de Lion (France)			Regression based on quantile-quantile plot
Polytechnic of Turin (Italy)		Multiple linear regression t-test F-test Chi-squared test VIF	
Tohoku University (Japan)	Multiple regression analysis Neural network		

Table 7 – Analysis methods used in the contributions for prediction

According to the goal of this Annex 53 "Total energy use in buildings: analysis and evaluation methods", the contributions that took into account the total energy use in buildings are highlighted in the following table.

	Total	Heating	Cooling	DHW	Electricity	Lighting	Other
Concordia University (Canada)	Building energy demand						
CETHIL, INSA de Lion (France)		X	X				
Polytechnic of Turin (Italy)		X	X		X		
Tohoku University (Japan)							
a)*	X	X	X	X			
b)**					X		
c)***	X						
d)*****	X	X	X	X	X	X	
Tohoku University (China houses)	X	X					
NTNU Trondheim (Norway)		X			X		
Polytechnic of Turin (Italy) - regional							
LBNL (U.S.) - national	X	X	X	X	X	X	X (oil fuel, Natural gas)

a)* houses in Sendai b)** peak electricity in 6 detached houses c)*** office buildings d)**** 80 households

Table 8 – Contributions taking into account the total energy use in buildings "

ESEMPI DI SCHEDE SINTETICHE RACCOLTE

Scheda 1

Name: Marcel
Field of investigation: individual building (multi-family houses)

1. Subject of the work

Type of building	International student dormitory
Dimension	320 rooms of 15 m^2 each
Location	Tokyo, Japan
Thermal characteristics	Low level of insulation and single-glazing windows with aluminum frame
Type of observed spaces	Single-room apartment
Year of construction	1989
No. of floors	5
Windows, orientation	One window each (either E, S, W)
Window opening	sliding
Shading devices	Fixed overhang
Sources of heat gains	Fridge, computer, lights, occupancy
Activity, sex and age of occupants	Students (M or F, 20-35)
Origin of occupants	27 different countries from 5 continents

2. **Aim of the work**
Analysis of individual differences in air-conditioning usage- and window-opening behavior-patterns and respective significant influences.

3. Database characteristics

Number of buildings	1	
Period of measurement	29.06.2007 - 13.08.2007	11.01.2008 - 11.02.2008
Duration (days)	46	32
Number of observed spaces	39	34
Number of observed spaces with window sensors	19	24
	Items	Interval
IF1. Climate	Outdoor air temperature, humidity, wind speed, solar radiance	2 minute
IF2. Building envelope	Not in database	
IF3. Building service & Systems		
IF4. Operation & Maintenance		
IF5. Indoor environmental quality	Indoor air temperature, humidity	2 minute
IF6. Occupants' activities and behavior	State of AC-unit (on/off/set-point temperature)[1)] Window state (open/closed)	Event
IF7. Social and economical aspects	Occupants personal preferences, individual characteristics (age, sex, height, weight), personal background (country of origin, sleeping habits during childhood, ...)	

[1)] not measured, but derived from data

4. Method/Methods applied for the data analysis
Multivariate linear and logistic regression analysis, model optimization through AIC and Nagelkerke's R2

5. Main results

As a result, statistical models of occupant-behaviour prediction including an exponentially weighted running mean of the outdoor temperature during the night and 17 individual factors such as above mentioned preference and thermal background were presented. Including these individual factors greatly increased the fit of the model to the data. It was found that, on the one hand, the running mean of the temperature has a similar impact to the individual factors in summer, while, on the other hand, the latter have a much higher influence in winter than in summer.

Related Publications

Schweiker, M. and Shukuya, M. (2009), Comparison of Theoretical and Statistical Models of Air-Conditioning-Unit Usage Behaviour in a Residential Setting under Japanese Climatic Conditions; Building and Environment 44: p. 2137-49.

Schweiker, M., Haldi, F., Shukuya, M. and Robinson, D. (2011), Verification of stochastic models of window opening behaviour for residential buildings, Journal of Building Performance Simulation,First published on: 09 June 2011 (iFirst)

Data are available for the partners? YES

Scheda 2

Authors: Stoyan Danov, JordiCarbonell (CIMNE, Spain)

Field of investigation: Nine individual office buildings in Spain

1. Subject of the work
The subject of work is the analysis of the energy performance of nine office buildings in Spain, corresponding to the climatic zone “D” according to the Spanish Building Technical Code. The dimensions of the buildings vary between 340 and 4820 m2.

2. Aim of the work
In order to improve the energy efficiency in existing buildings and to design appropriate energy-saving measures, it is important to analyze separately the influence of the building (envelope, energy systems) from the influence of the human behavior factors (heating/ventilating choice, system control).

At the present work three parameters are taken as building performance indicators: the total heat loss coefficient (Ktot), effective heat capacity and the solar contribution to heating load.
The total heat loss coefficient is a measure for the heat loss through the building’s envelope from transmission and ventilation, and can be used as indicator for comparing the performance of different buildings.
The solar contribution to the heating is another parameter characterizing the building.
The effect of the heat capacity on the energy consumption of the building depends on both the building structure and its use. It can be used as indicator for the operation of the heating system, with higher values indicating intermittent heating.

The aim of the work is to calculate and analyze the three parameters for a group of individual buildings and attempt to establish criteria for their interpreting, in order to reveal potential for energy savings. For the calculation the adopted method uses daily energy consumption data, building use schedule and readily available meteorological data. With the increasing application of smart meters for billing by the utility companies, the method can be used for characterization of large stock of buildings without additional measurement cost.
The analysis can also be used for alert refinement in BEMS and generation of improved recommendations.

3. Database characteristics

The database contains data for nine office buildings. The original database contains hourly data, but the data used in the present work is based on daily integrated data.
The recorded items include:

- Net building area
- Efficiency of the heating equipment Consumed fuel energy (hourly)
- Consumed electrical energy (hourly)
- Number of occupants in the building (hourly) –
- External temperature (hourly) –
- Global solar irradiation (hourly) –

4. Method/Methods applied for the data analysis

The method uses linear regressions based on daily data for determining of the total heat loss coefficient, the effective thermal capacity of the building and the solar contribution to the heating load. Subsequently the total heat loss coefficient is recalculated, accounting for the accumulated heat and the solar radiation influence in order to obtain estimation closer to the real value.

An improved estimation of the total heat loss coefficient is achieved after explicit corrections for the accumulated heat and the solar radiation are introduced in the heating load. This is observed by the improvement of the determination coefficient and the standard error for the regression.
Once the heat accumulation and the solar radiation effects are accounted for, the remaining scatter of the data is mainly due to the human behavior factors.

5. Main results

The total heat loss coefficient, the effective heat capacity and the solar radiation contribution have been calculated for the 9 buildings. The results are compared and the differences are investigated with the available more detailed hourly consumption profiles.

In all of the cases the correction for the heat capacity effect improved the linear regression for the total heat loss coefficient. The correction for the solar radiation improved the linear regression for the heat loss coefficient in more than the half of cases, but in some cases led to deterioration. The different situations are presented and analyzed.

Related publications

C. Ghiaus, Experimental estimation of building energy performance by robust regression, Energy and Buildings 38 (2006) 582-587.

J.-U. Sjögren, S. Andersson, T. Olofsson, An approach to evaluate the energy performance of buildings based on incomplete monthly data, Energy and Buildings 39 (2007) 945-953.

J.-U. Sjögren, S. Andersson, T. Olofsson, Sensitivity of the total heat loss coefficient determined by the energy signature approach to different time periods and gained energy, Energy and Buildings 41 (2009) 801-808.

Data are available for the partners? NO

PUBBLICAZIONI REDATTE RELATIVE AL TEMA:

- Statistical analysis methods to investigate Energy use in buildings
  Corgnati S. P., Fabi V., Talà N., Filippi M., Proceedings of 3rd International Conference on Passive and Low Energy Cooling for the built Environment (PALENC 2010), Rodhes Island, Greece, 29 Sett-01 Oct 2010

  ABSTRACT

If, in one hand, the recent energy regulations addressed to the new and retrofitted building try toimprove the energy performance of buildings, in the other hand, the large part of the nationalbuildings stocks all over the word is old and with very poor energy saving qualities.
The forecast of actual energy consumption in existing buildings is one of the major topics facedby the research in the last year: the energy demand of the building sector is continuously increasingespecially due to a significant rise of the electrical energy requirements.
The poor information about the thermo-physical characteristics of the existing buildings and thedifficulties to develop reliable “direct methods”, is pushing the research to deepen the potentialitiesof “inverse methods” application for the energy consumption prediction.
When inverse methods are applied, the first step of the study is dedicated to statistical analysesaimed at showing the key factors related to and influencing the building energy consumption.
Then, according to the quality and typology of the collected data, suitable inverse methods can beinvestigated and applied.
Looking at the extreme situations, the study can be finalized to different goals. One is the analysisand forecast of energy consumption of large building stocks: in this case, typically, a wide number ofbuildings, each of them characterized by a few number of building parameters, is known. On theother extreme, the object of the analysis is one single buildings, being known very detailedinformation about its parameters.
Anyway, the ultimate goal is the same: the prediction of future consumption by mean of dedicatedinverse methods and this is the challenge of Sub-Task C of IEA-ECBCS Annex 53. To score thisgoal, a large literature review is firstly developed, focused on both large stocks and single buildings.
This paper introduces some basic aspects of statistical analysis and prediction method suitable forenergy consumption investigations. Moreover, from the devoted literature review developed inAnnex 53, some significant experiences about the application of “inverse methods” are presented andcritically discussed.

- Definition of building typologies for energy investigations on residential sector by tabula iee-project: application to Italian case studies
  Ballarini I., Corgnati S. P., Corrado V., Talà N., Proceedings of 12th International Conference on Air distribution in rooms-ROOMVENT 2011. Trondheim, Norway, 19-22 June 2011

  ABSTRACT

The Building Typologies are a set of model buildings with their own age of construction,geometrical, thermo-physical, equipment and energy performance properties. Their definition is afundamental step addressed to different goals:

- identify the building types with the poorest energy performance;
- estimate the energy saving potentials of different refurbishment strategies;
- simulate and monitor the effect of specific policies and measures;
- develop analyses for energy advice, portfolio assessment or energy saving potential (at local,national or European level).

Within this scenario, the IEE-Project TABULA is aimed to create a harmonized structure forEuropean Building Typologies, focusing on residential buildings: the topic of the research is how tocollect, elaborate and analyze data characterizing national building stock in order to define "typical"buildings able to express a Building Typology.
In fact, different strategies with different level of information details can be adopted for"typical" building definition.
In this paper, the different approaches for defining the "building typologies" are presented andtested in TABULA project are firstly introduced. In particular, three methods are explained to showthe developed benchmark models: the first method identifies building types based on severalassumptions deduced by an expert without statistical data; the second method processes empirical datato pick out real buildings that are representative of the stock; finally, the third method provides abuilding that is the most probable of a group of buildings.
Then, these approaches are applied to some Italian case studies: example buildingcharacteristics, statistical analysis on residential building database, Italian building typologiesstructures are shown.
Moreover, critical aspects faced in the project and potentialities/limitations of the performedanalyses are critically discussed.

- Improving energy modeling of large building stock through the development of archetype buildings
  Ballarini I., Corgnati S. P., Corrado V., Talà N., accepted at 12th International Conference of the International Building Performance Simulation Association. Sydney, Australia, 14-16 November 2011

  ABSTRACT

In this paper a selection process, based on statistical techniques, of representative buildings is presented. Starting from a real estate stock it is possible to draw a sample and calculate the relevant sample statistics. As second step, their elaboration permits to pick out real buildings with geometrical and thermo-physical characteristics similar to the average of the building sample. In addition, the results of this method are compared to those obtained by segmentation (or cluster) analysis, that is a method to partition a set of houses into groups having similar profiles.
Finally, using the Piedmont Regional Database of Energy Performance Certificates these approaches are applied in order to verify the reliability of the analyses proposed. Potentialities and limitations of the performed analyses are critically discussed, as well.

- Building Typology Brochure-Italy

  Corrado V., Ballarini I., Corgnati S. P., Talà N., Report del Progetto Europeo n. IEE/08/495, ISBN: 978-88-8202-070-5, Dicembre 2011

ABSTRACT

Il progetto TABULA (TypologyApproach for BUiLding stock energyAssessment), finanziato dal programma europeo Intelligent Energy Europe, mira a creare una struttura armonizzata delle tipologie edilizie europee, con unparticolare focus sugli edifici residenziali.
Ogni tipologia nazionale è costituita da un insieme di edifici residenziali modello con tipiche caratteristicheenergetiche. Ciascun edificio rappresenta un determinato periodo di costruzione e una specifica dimensione. Gliedifici-tipo vengono utilizzati in ciascun paese come mezzo per rendere nota la prestazione energetica ed ipotenziali di risparmio energetico raggiungibili attraverso azioni di riqualificazione dell'involucro edilizio e degliimpianti termici. Si prevedono due livelli di riqualificazione dell'edificio-tipo: una "riqualificazione tipica",mediante l'applicazione di misure comunemente utilizzate all'interno del paese, ed una "riqualificazione avanzata",attraverso l'introduzione di interventi che riflettono le migliori tecnologie disponibili.
Le potenzialità di risparmio energetico sono valutate utilizzando la metodologia di calcolo fornita dalle normetecniche europee a supporto della Energy Performance of Buildings Directive (EPBD, 2002/91/CE) e confrontandola prestazione energetica prima e dopo la riqualificazione. Informazioni aggiuntive sulla frequenza delle tipologieedilizie ed impiantistiche renderanno possibile l'utilizzo della classificazione tipologica come modello per la stimadella prestazione energetica del parco edilizio globale su scala nazionale.
Il progetto è rivolto agli esperti che lavorano su analisi di scenario, così come a chi prende le decisioni politichea vari livelli (regionale, nazionale, comunitario). Anche i consulenti energetici possono utilizzare le tipologie per lefasi iniziali di una consulenza.
I risultati principali del progetto TABULA sono i seguenti:
- Struttura della tipologia edilizia/impiantistica

E' sviluppata una struttura comune per le tipologie edilizie sulla base delle tipologie nazionali già esistenti per gliedifici residenziali e gli impianti termici. Tale struttura considera i diversi tipi di costruzione diffusi nel paese. Lasua presentazione segue le esigenze dei gruppi target e degli attori coinvolti nel progetto.
- Dati relativi alla tipologia edilizia

La struttura della tipologia edilizia viene completata con i dati nazionali di ciascun paese partecipantecomprendenti:

- dati tipologico-dimensionali;
- parametri termo-fisici dei componenti d'involucro;
- prestazioni degli impianti termici;
- distribuzione statistica dei diversi tipi di edificio ed impianto nel parco edilizio nazionale;
- possibili interventi di risparmio energetico, distinti in due livelli, "tipico" e "avanzato".

- Webtool delle tipologie edilizie

I dati relativi alla tipologie edilizie elaborati nel corso del progetto saranno pubblicati attraverso uno specialeWebtool delle tipologie edilizie. Per ogni paese partecipante la tipologia nazionale sarà presentata nella forma diuna matrice con fotografie degli edifici-tipo, organizzata secondo il periodo di costruzione e le dimensionidell'edificio. Per ogni tipo di edificio saranno fornite informazioni sulla distribuzione statistica, sui tipici impiantitermici, sulle prestazioni energetiche medie. Inoltre sarà indicato il potenziale risparmio energetico e laconseguente riduzione dell'emissione di biossido di carbonio.
Selezionando un tipo di edificio si avrà accesso alle schede dei dati sulla costruzione e sugli impianti termici.

Per ogni tipo di edificio di ogni paese potrà essere effettuato un calcolo on-line per valutare la prestazioneenergetica dell'edificio nel suo stato originario e il risparmio energetico ottenibile mediante l'applicazione di uno opiù interventi selezionabili dall'utente.

Nel presente fascicolo è illustrata la struttura tipologica sviluppata all'interno del progetto TABULA conparticolare riferimento alla tipologia edilizia nazionale. Una particolare attenzione è rivolta alla definizione degliedifici-tipo all'interno della classificazione tipologica. Sono inoltre presentati i dati relativi alla tipologia costruttivae impiantistica italiana. Una sezione specifica del fascicolo, organizzata sottoforma di schede illustrative, è dedicataall'analisi energetica degli edifici-tipo, con l'indicazione del risparmio energetico conseguibile a seguito diinterventi di riqualificazione sull'involucro edilizio e sull'impianto termico.

Appendice

Curriculum scientifico del gruppo di lavoro

Marco Filippi

Marco Filippi, born in 1944, is mechanical engineer and full professor at Politecnico di Torino.

Since 2005 he is Vice-Rector of the Politecnico; before he was member of the Academic Senate (2001-2005), Deputy Dean of the First Faculty of Architecture (2000-2005) and Director of the Interdepartmental Centre for Didactic Services at the Faculty of Architecture (1997-1999).

He acts for the Politecnico di Torino in the executive board of the Centre for Conservation and Restoration of Cultural Heritage "La VenariaReale" (http://www.centrorestaurovenaria.it).

In the Department of Energy at Politecnico di Torino he leads the research group TEBE (http://www.polito.it/tebe).

TEBE is generally working on energy efficient buildings, indoor environmental engineering, lighting and acoustics and in this context he works on sustainable architecture, technological innovation in building design and energy management in existing buildings.

At the end of the eighties he founded the Laboratory for Environmental System Analysis and Modelling (LAMSA). In 2000 he founded the Centre for Research and Experimentation in Natural and Artificial Lighting (CERSIL) at Environment Park, a scientific and technological park in Torino; in the centre the first Italian "artificial sky" is operating.

He acts for Italy in the Air Conditioning Commission of the International Institute of Refrigeration and in the Annex 53 "Total Energy Use in Building - Analysis and Evaluation Methods" of the International Energy Agency.

He is member of the scientific committees of the Superior Institute for Territorial Systems and Innovation SiTI (http://www.siti.polito.it) and of the Green Building Council Italia (www.gbcitalia.org).

Already member of the scientific committee of the centre "Gino Bozza", in the national council for research CNR ("Consiglio Nazionale delle Ricerche"), concerning causes of deterioration and methods of conservation of the works of art, in 1999 he was selected as member of the team, created by the ministry for the conservation of cultural heritage (Ministero per iBeni e le Attività Culturali), for the definition of guidelines about standards for management and development of the Italian museums (D.M. 10 maggio 2001). At present he is member of the regional committee for the application of the quality standards in museum buildings.

He is author and co-author of over three hundred and fifty scientific papers, didactic papers, chapters of books and editorials.

He is co-editor of the books "Impianti di climatizzazione per l'edilizia: dal progetto al collaudo (HVAC installations in buildings: from design to commissioning)", printed by Masson in 1997 and fully diffused in the Italian community of HVAC designers, "Agenzia Torino 2006_Progetti" and "Agenzia Torino 2006_Cantieri e Opere", printed in 2004 and 2006 by Electa-Mondadori on the occasion of the 20th Winter Olympic Games, and "Certificazione energetica e verifica ambientale degli edifici (Energy certification and environmental assessment in buildings)", printed by Flaccovio in 2007.

He is director of the book collection on "Energy and Environment" edited by CELID (Torino).

Since 1993 to 1995 he was editor of the monthly magazine "Condizionamento dell'aria (Air conditioning)" and at present he is member of the editorial board of the International Journal of Building Science and its Applications "Building and Environment" edited by Elsevier.

In Politecnico di Torino he teaches building physics and building services in the First Faculty of Architecture and he is director of the Doctorate "Technological Innovation in Built Environment".

Since 2003 to 2006 he was director of the Master "Facilities Management for real estate" organized by the Consorzio per la Ricerca e l'Educazione Permanente (COREP).

In the last years he gave lectures on building physics, sustainable building, indoor environment control for human comfort and cultural heritage conservation, building services in historical buildings in degree and doctorate courses, masters and postgraduate schools in Italy.

In the past he worked as HVAC designer. At present he operates as consulting engineer as regards efficient use of energy, indoor environment engineering and technologies for preservation of architectural and artistic heritage. In this context he is frequently charged by public and private bodies as supervisor of building design and construction processes and facilities management contracts.
He is also scientific director of the company Onleco (www.onleco.it), born (2001) in the Incubator I3P of the Politecnico di Torino and which is active in the fields of acoustics, lighting, energy management, indoor environment monitoring, HVAC commissioning and sustainable building.
From 1990 to 1992 he was president of the Società degli Ingegneri e Architetti in Torino (SIAT), a society of engineers and architects established in Turin in the second half of the XIX century.
From 1993 to 1995 he was president of the Associazione Italiana Condizionamento dell'Aria Riscaldamento Refrigerazione (AICARR), the Italian society of the engineers involved with air conditioning, heating and refrigeration and president of the national standard committee for air conditioning and refrigeration.
He is honorary member of AICARR, member of the American Society of Heating Refrigerating and Air Conditioning Engineers (ASHRAE), and member of Italian societies in the fields of thermal engineering, lighting and acoustics.

Stefano Paolo Corgnati

Stefano Paolo Corgnati, graduated with honors in Mechanical Engineering and Ph.D in Energetics, is Associate Professor at the Energetics Department of the Politecnico di Torino, where he teaches building physics, building energy systems and sustainable building design at the 1st Faculty of Architecture.He works in the TEBE research group (www.polito.it/tebe) focusing on energy&buildings and indoor environmental control.
He is Vice-President of Rehva (Federation of HVAC European Associations) and member of Rehva Board of Directors.
He is member of the Directive Board of AICARR (Italian Association of Air Conditioning) and AICARR delegate for relations with Rehva.
He is the author of more than 180 scientific, technical and didactic publications, mainly concerning: radiant panels technologies, objective and subjective assessment of indoor environmental comfort, thermal mass activation techniques, energy certification and demand of existing buildings. For the quality of his research activity, he won in 2009 the Rehva "Young Scientist Award". Moreover, in 2011 he was nominated "Rehva Fellow".
He is involved in a number of National, European and International Research Projects on building energy consumptions.
He is sub-task leader of the research project Annex 53 "Total Energy Use in Buildings" of the International Energy Agency (IEA-ECBCS). He is chair of the REHVA Task Force on "Indoor Climate Quality Assessment".
He is the operative manager of the Research Competence Centre TI-Green of Politecnico di Torino & Telecom about smart energy monitoring in buildings.
From 2008 to 2010, he was member of the Editorial Board of the Journal "CDA" (Condizionamentodell'Aria, Air Conditioning) and of the following "AICARR Journal", official journals of AICARR.
In 2009 and 2010, he was coordinator of the working group of Politecnico di Torino aimed at supporting Piedmont Region for the implementation and application of Building Energy Certification.

Valentina Fabi

Valentina Fabi, graduated in Architecture (Building) in 2008, is actually a PhD student at the Energetic Department of the Politecnico di Torino. She works in the TEBE research group (www.polito.it/tebe) focusing on the influence of occupant behavior on energy consumption and indoor environmental quality.
She is collaborating with Danish Technical University (DTU), where she spent part of her course of study for eight months.
She is author of 11 scientific and technical publications, including national and international journals, international conferences and chapters of books. Her studies, focused in the beginning on the microclimatic

quality in indoor environment, especially in museums, are now focusing on the study related to the occupant behavior in buildings, with the aims of a better prediction of the building performances.
She is partner of the research project Annex 53 “Total Energy Use in Buildings” of the International Energy Agency (IEA-ECBCS) and she is collaborating in team of task-force related to the “Occupant behavior” and Sub-Task C “Statistical analysis”.
In 2013 she is going to defend a Ph.D thesis entitled “The influence of occupant behavior on energy consumption and indoor environmental quality”.

Novella Talà -
Novella Talà received the Masters' Degree in Civil Engineering from the Politecnico di Torino in 2003. For the period October 2003-March 2008, she worked for building companies as in construction/building manager.
She is currently an Assistant Researcher with the Department of Energy at Politecnico di Torino. His research activity mainly lies in the area of statistical analysis methods to investigate energy use in buildings and to predict building energy consumptions.
Dr. Talà is coauthor of more than 10 international conference papers and industrial internal reports. She collaborates with ENEA, TELECOM for national projects and with many academic and industrial institutions for the european projects ANNEX, BECA.