Energy Conversion and Management 90 (2015) 323–335

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

Historical trends and current state of heating and cooling degree days in Italy

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A R T I C L E I N F O

Article history:
Received 2 September 2014
Accepted 11 November 2014
Available online 5 December 2014

Keywords:
Energy demand
Building
Degree days
Climatic trend
Consumption forecasting

A B S T R A C T

Degree days (DD) represent a versatile climatic indicator which is commonly used in the analysis of building energy performance, as e.g. (i) to perform energetic assessment of existent and new buildings, (ii) to analyze the territory energy consumption, (iii) to develop scenario analyses in terms of energy consumption forecasting, and so on.

Different methods can be used for determining the DD values, depending on the available climatic data of each location. In the present paper, the simplified methods based on reduced climatic data set have been compared assuming the mean daily degree-hours method (MDDH) as reference. Hourly temperature profiles recorded by the meteorological station located at the University of Genoa have been used for these analyses.

In the second part of the present work, the ASHRAE method has been selected to calculate heating (HDD) and cooling (CDD) degree days for several Italian cities. In particular, daily meteorological data of several Italian cities (covering the whole climatic conditions which occur in Italy) have been used to calculate heating and cooling degree days in the period 1978–2013, in order to analyze their trends in the last years. Finally, the historical profiles of Rome and Milan have been treated as time-series and analyzed in the frequency domain, performing a decomposition of the original data set into different characterizing components. This simplified approach permits to deeply analyze the historical profile of DD and represents a simple starting point method for future analyses with forecasting perspectives.

1. Introduction

The global increase of energy demand has assumed a paramount international importance in order to attempt to reduce the CO_2 emissions and to mitigate the climate change.

In this context, the buildings sector has collected a strong interest, considering that in Europe it is responsible of about 40% of the total energy consumption, with more than 25% due only to the residential segment, representing the largest sector in all end-users in Europe [1]. In Italy, energy consumption due to the civil sector was about the 37% of the total energy demand in 2012, as highlighted in the last report of the Ministry of Economic Development [2].

In order to achieve relevant savings of primary energy, several potential mitigation measures have to be implemented with reference to all the possible aspects of the building design (envelope, internal condition, heating/cooling systems, renewable energies, etc.), starting from the earliest design phase and with an optimization perspective. Hitherward, the 91/2002 "Energy Performance of Buildings Directive" (EPBD) [3] has been emanated to introduce several requirements for new and existent buildings within EU.

This topic represents a crucial issue also considering that the energy demand for heating and cooling purposes tends to rise, especially due to the increasing consumption of developing countries and to the climate changes.

In particular, a double effect has been assessed: (i) a decrease of the global heating energy demand by over a 30% from one side and (ii) an increase of the cooling energy demand by about 70% on the other side [4].

Li et al. [5] analyzed the most important studies on the impact of climate change on energy use in the building sector concluding that the most significant adverse impact would occur in the hot summer and warm winter climate zone, in which building energy use is generally dominated by cooling requirement. Moreover, considering that space heating is provided largely by oil or gas-fired boiler plants, whereas space cooling mainly relies on electricity, a

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http://dx.doi.org/10.1016/j.enconman.2014.11.022
0196-8904/

Nomenclature

Roman letters

CDD	cooling degree days [°C]
DD	degree days [°C]
D_t	total number of days
E	energy consumption [kW h]
$f(Z)$	probability density function
$F(Z)$	cumulative normal probability function
GDD	growing degree-days [°C]
H	global building transmission coefficient [W K^{-1}]
HDD	heating degree days [°C]
N_m	number of days in a month
T	temperature [°C]
$\overline{T}_{e,d}$	mean daily external temperature [°C]
$\overline{T}_m$	mean monthly external temperature [°C]
T_m	monthly mean temperature [°C]

Greek letters

δ	percentage deviation [%]
ΔT_m	difference between base and monthly mean temperature [°C]
σ	standard deviation
φ	latitude [°]
η	efficiency

Subscripts

b	base temperature
cs	cooling system
d	day
e	external
h	hour
hs	heating system
m	month
t	total

shift toward electrical power demand can occur with significant implications for the energy and environmental policy in a nationwide perspective.

The estimation and prediction of building energy demand represents a crucial point in order to perform scenario analyses able to detect the necessary policy measures. The degree-days method represents one of the simplest ways to estimate the building energy consumption, without performing heavy calculations and permitting to process a lot of data.

Generally, the degree days are an important climatic parameter used in a lot of fields (energy, architecture, agriculture, entomology, etc.) and based on the idea to capture the variations of the outdoor temperature, in terms of amplitude and frequency, with respect to a reference temperature, also called "base temperature". In building application the reference temperature is the temperature which allows achieving the comfort condition and, consequently, the heating/cooling system is turned off. As heat losses in static conditions are directly proportional to the difference between internal and external temperature, the monthly energy consumption $E_{h,m}$ can be calculated as in Eq. (1) [6], where: H (in W/K) is a global building transmission coefficient, t_h is the heating time in a day (which can be assumed equal to 24 h if a continuous heating/cooling is provided), $\eta_{hs/cs}$ is the efficiency of the equipment and DD_m is the total heating or cooling degree days of a month m.

$$E_m = \frac{H \cdot DD_m \cdot t_h}{\eta_{hs/cs}} \quad (1)$$

This relationship between degree days and energy consumption is for instance evidenced in Fig. 1, where the heating energy demand, of a benchmark building, as a function of HDD is reported for several European cities [7].

The importance of the degree days approach lies in their capability to perform fast analyses in various fields and with different purposes. In building applications, the main purposes can be summarized as following:

- Energetic assessment for existent building in a maintenance and renovation perspectives.
- Energetic performance predictions for new constructions in preliminary design stage.
- Analyses on the actual state of the territory energy consumption takes into account the existent building stocks, the heating/cooling system typologies and the demographic distribution.
- Construction of scenario analyses in terms of energy consumption forecasting, also in an economic perspective, with the aim to select the suitable policy measures which guarantee the highest energy saving.

Degree-days have been used for estimating heating energy consumption in buildings since 1934 [8]. In the last years, a lot of works have been conducted in order to formalize their use in the prediction of energy demand of buildings, to quantify their values for different countries and their calculation uncertainties [6,9–12].

The first attempt to realize a dataset of heating degree-days was performed by Thom [13], who conducted statistical analyses on the seasonal degree-days in order to provide methods and charts for any location in the United States. In 1981, Hitchin [14] utilized temperature records at several sites in Britain to investigate the variations of the annual and monthly heating degree-days, analyzing the effect of changing the base temperature. An extension of this work can be found in [15] in which several methods to estimate the building heating energy requirement based on HDD are described.

More recent works have been conducted for other countries (as e.g., Romania [16], Turkey [17–20], Australia [21], Greece [22,23], China [24–26], Spain[27] , Switzerland [28], Saudi Arabia [29,30],

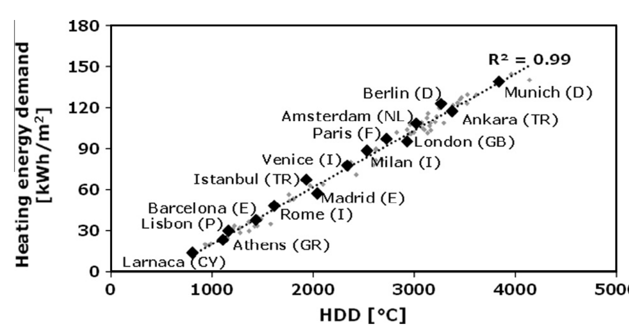

Fig. 1. Heating energy demand as a function of heating degree days (HDD) for a benchmark building [7].