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Degree Days and Building Energy Demand

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ABSTRACT

Degree-days (DD) are a climatic indicator that can be used in the assessment and analysis of weather related to energy consumption of buildings. Essentially, degree-days are a summation of the differences between the outdoor temperature and some reference (or base) temperature over a specific time period. In literature, different method can be used for determining the DD value and generally the choice depends on the availability of climatic data of each location. In this paper, after a review and comparison of the most common approaches used to determine DD, the Italian procedure was deeply analyzed. The application of Italian technical rules is based on weather data calculated on a monthly time series monitored before 1994. The obsolescence of the used weather data leads to an incorrect assessment of energy performances. Taking into account the climatic change that in the last years has affected Italy land, the aim of the paper is to assess the impact of new DD values in calculating energy demand of buildings.

For these reasons, in this paper the authors recalculated DD of some Italian cities, considering the average monthly temperatures of the last decade. Data were extracted from Meteonorm 7, one of the most popular software for the statistical processing of climate data. Furthermore, other datasets were generated considering future scenarios defined by IPCC (Intergovernmental Panel on Climate Change). A comparison with the official DD issued by current legislation and new DD recalculated with more recent data highlighted how climate change have affected the calculation of this parameter.

INTRODUCTION

The adverse effects on the earth climate due to the global increasing demands of energy, have become the matter of concern for people of over the world. The rise of atmospheric temperatures due to climate change may mean that historic 20-year averages used for energy planning will not be appropriate, and the rate of temperature rise in the near future will dictate how reliable these values will be for setting energy budgets [1].

The outdoor temperature variations directly affects water resources, power generation, agriculture, construction and in particular the energy consumption for cooling and heating of buildings [2]. Indeed, several case studies [3-8] have indicated considerable impacts of temperature changes on energy consumption in buildings. Since 1934, one the simplest ways to estimate the energy consumptions in building is the Degree-Days (DD) [9].

Usually, the DD calculation is accepted as an index of energy consumption for heating and cooling of the buildings and represents a simplest method used in Heating, Ventilating and Air-Conditioning industries to estimate heating and cooling energy requirements. Essentially, it is the summation of temperature differences over time and hence it capture both extremity and duration of outdoor temperatures; the temperature difference is calculated between a reference temperature and the outdoor air temperature. The reference temperature for buildings is a known variable (base temperature); a possible definition for base temperature could be: the outdoor temperature at which the heating/cooling systems do not need to run in order to maintain comfort conditions. The base temperature is central to the successful understanding and use of DD [1]. In an heated building, during cold season, heat is lost toward the external environment; some of this heat is replaced by casual indoor heat gains, by people, lights, machines and solar gains, while the other part of the heat is supplied by the heating system.

In addition to the base temperature, it is very important the outdoor temperature value. A variation of this value could lead to an incorrect estimation of DD and subsequently an error in the evaluation of building energy demand.

NOMENCLATURE

DD	[-]	Degree Days
EPi,c	[kWh/m^{2}year]	Energy performance index for cooling period
$EP_{i,DWH}$	[kWh/m^{2}year]	Energy performance index for the production of domestic hot water
$EP_{i,gl}$	[kWh/m^{2}year]	Overall Energy performance index

$EP_{i,h}$	[kWh/m^{2}year]	Energy performance index for heating period
$EP_{i,l}$	[kWh/m^{2}year]	Energy performance index for artificial lighting
S	[m^2]	Surface which delimits the heated volume to the outside
T_i	[°C]	Reference indoor thermal comfort temperature
T_r	[°C]	reference outdoor thermal comfort temperature
T_s	[°C]	Second reference outdoor temperature (12°C)
V	[m^3]	Heated indoor volume

For example, in London and Edinburgh from 1976 to 1995 the degree days value felt by around 10% [10]. Consequently, it is possible that heating degree days could fall by 30%-40% in the UK by the 2080s, due to a constant increment of outdoor temperature. In this contest, it will be important to evaluate the impact of the climate change on the estimation of DD and building energy consumption. More recent works have been carried out for different countries: Romania [4], Turkey [11, 12,13], Australia [14], Greece [15], China [16,17], Spain[18] , Switzerland [8], Saudi Arabia [19, 20], Morocco [21]. Indeed the correct estimation and prediction of the building energy demand represents a crucial point in order to perform scenario analyses able to determine the best policy to comply the requirements for new and existent buildings ruled by European Union (EU, 91/2002 Energy Performance of Building Directive – EPBD) [22] and others countries.

DEGREE DAYS: DIFFERENT DEFINITIONS

Degree days for a location is defined as the sum, extended to all days of a conventional twelve-month period, of only the positive differences between the daily temperature and the daily average temperature. In the case of Heating Degree Days (HDD) are computed only the differences between outside and base temperature whenever the outside temperature falls below the base temperature, during heating period. On the contrary, the Cooling Degree Days (CDD) are computed only the differences between outside and base temperature whenever the outside temperature exceeds the base temperature, during the cooling period.

There are several ways to determine DD [1,18]:

- mean degree-hours: calculated from the hourly temperature records (as the Italian calculation method);
- daily maximum and minimum temperatures: e.g. the Meteorological Office equations that uses mean daily temperatures;
- mean daily temperature DD, is used in some country such as in USA, as defined by ASHRAE [23] and Germany [24]
- direct calculation of monthly DD from mean monthly temperature and the monthly standard deviation; e.g. Hitchin's formula [25-30].

OTHER METHODS

In literature, it is possible to find other methods. For example, ASHRAE recommends the method by Erbs [29], similar to Hitchin, for estimating monthly degree-days. There are also reports of individual energy managers adopting their own techniques based on the kind of weather data that is available to them. However, it should be noted that Equation (1) should always be the preferred option if suitable hourly data and adequate data processing tools are available.

THE ORIGIN OF ITALIAN DD

The determination of the DD is fundamental in the correct evaluation of the energy needs of a building-system in relation with meteorological conditions. The attention to energy saving and the subsequent release of the first relevant standards born in 1974 after the first energy crisis.

Italy reacted to this problem by amending a law [31] and then updating by art. 37 of law [32], which for the first time stated the principle of modern energy saving concepts in terms of plant design and thermal insulation of buildings. The [31] was implemented with the decrees [33-36]. For the first time, in the DM [34] are tabulated the Italian DD. According to the definition of DD, for a given location, fixed a reference indoor thermal comfort temperature T_r (20°C), DD are calculated according to the following formula:

$$DD = \sum_i \left(T_r - T_i \right) \qquad (1)$$

where the sum is extended to all days of the year in which the average daily temperature T_i is lower than a second reference temperature T_s ($\geq T_r$) conventionally fixed.

ITALIAN CLIMATE CONTEXT

The Italian region is between the 47th and the 36th parallel north, located almost in the centre of the temperate zone of the northern hemisphere.

From a general perspective Italian climate is also favoured by the large body of water of the Mediterranean Sea that surrounds almost every side. Mediterranean Sea can be considered as a beneficial reservoir of heat and humidity that determines a particular zone often called "temperate Mediterranean" (Figure 1).

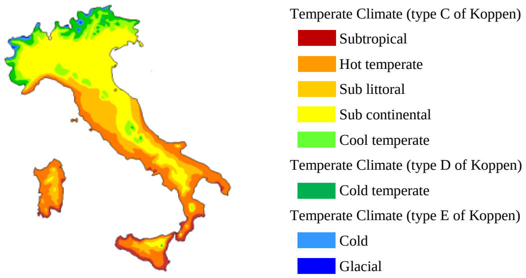

Figure 1 Climate map of Italy according to M. Pinna

The climate varies considerably from the north to the south of Italy. In the north of the country, the climate is harsh, with very cold winters and very hot and particularly humid summers, due to the presence of Alps and Apennines. The Alps, not only are a sort of barrier for cold currents coming from the Arctic regions of northern Europe, but also for the temperate but wet air masses from the North Atlantic. In addition, the Alps surround (along with facing the Northern Apennines), a closed basin, subject to atmospheric subsidence, with stagnant air in the lower layers. This basin area called “Po-Venetian”, have an independent climate, different from that of the surrounding areas of south-eastern France, Switzerland and Austria. Also in this context, the presence of the Adriatic Sea, long and shallow (especially near the coast) and sandwiched between two peninsulas (the Italian and Balkan) gives a limited beneficial effect: its influence is much less important than that exercised by the wider and deeper Tyrrhenian Sea, on the western side of the Italian peninsula [37]. In central Italy, the climate is milder, with a smaller difference in temperature between summer and winter and a shorter and less intense cold season than in the north; summers are longer, but the sultriness of the northern cities is mitigated by the sea. In southern Italy and the islands, winters are never particularly harsh, and spring and autumn temperatures are similar to those reached in the summer in other areas of Italy [38]. Temperatures vary widely in Italy, in the north, centre or south of the country. The summer can be quite hot, mainly in the south of the peninsula, with high nocturnal temperatures of usually 28-33°C, but sometimes-even 40°C. Thunderstorms are quite common especially in the northern areas. Hot air rising from the sea can cause heavy thunderstorms especially in early fall, but these bring often the only summer rain that rapidly evaporates. In spring and fall, the *Scirocco*, a warm wind from Africa, raises the temperature of the peninsula. In the summer these winds can bring very hot, unpleasant weather, sometimes even up to the northern districts of Italy [39].

PRIMARY ENERGY DEMAND AND DD

According to the “National guidelines for energy certification of buildings”[40] , the Italian buildings classification is based on an index of overall energy performance (EP_{gl}) defined as follows:

$$EP_{i,gl} = EP_{i.,h} + EP_{i,DHW} + EP_{i,c} + EP_{i.,l} \quad (2)$$

where:
$EP_{i,h}$ = energy performance index for heating period;
EP_{DHW}= energy performance index for the production of domestic hot water;
EP_c = energy performance index for cooling period;
$EP_{i,l}$ = energy performance index for artificial lighting.

The determination of E_{gl} permits to identify the energy class of a building, each identified by a letter from A, the best class, to G, the worst class. The class of a building should be included in the energy performance certificate. The energy certification is applied to buildings of all the categories laid down in Art. 3 of [36] depending on use. In the case of residential buildings, category *E.1(1): residential building with permanent occupation*, all the above indexes are expressed in kWh / (m^2 • year); in the other cases in kWh / (m^3 • year).

Nowadays, in Italy among the indexes of Equation (2), are required only the calculation of $EP_{i,h}$ and $EP_{i,DHW}$;, therefore it is assumed:

$$EP_{i,gl} = EP_{i.,h} + EP_{i,DHW} \quad (3)$$

The annual consumption of primary energy for heating and production of domestic hot water should be less than the prescribed limit (Annex C of [41]):

$$EP_{i,gl} < EP_{i,\lim it} \quad (4)$$

The limits of building energy demand, for heating period, applicable from January 1, 2010, in the following tables (Table 1 and Table 2) are shown:

Table 1 Values of $EP_{i,limit}$ for space heating applicable from January 1, 2010 for residential buildings in kWh/m^2year

S/V	Climatic Zone									
	A	B		C		D		E		F
	Up to 600 DD	from 601 DD	To 900 DD	from 901 DD	To 1400 DD	from 1401 DD	To 2100 DD	from 2101 DD	To 3000 DD	Over 3000 DD
< 0.2	8.5	8.5	12.8	12.8	21.3	21.3	34	34	46.8	46.8
≥ 0.9	36	36	48	48	68	68	88	88	116	116

Table 2 Values of $EP_{i,limit}$ for space heating applicable from January 1, 2010 for other buildings in kWh/m^3year

S/V	Climatic Zone									
	A	B		C		D		E		F
	Up to 600 DD	from 601 DD	To 900 DD	from 901 DD	To 1400 DD	from 1401 DD	To 2100 DD	from 2101 DD	To 3000 DD	Over 3000 DD
< 0.2	2	2	3.6	3.6	6	6	9.6	9.6	12.7	12.7
≥ 0.9	8.2	8.2	12.8	12.8	17.3	17.3	22.5	22.5	31	31

The limit values given in the tables are expressed as a function of Climatic Zone, as identified in Article 2 of [36], and the ratio index of the building S/V, where:

a) S, expressed in square meters, is the surface which delimits the heated volume V to the outside;

b) V is the gross volume, measured in cubic meters, of the heated building, delimited by surfaces that surround it.

For values of S/V in the range from 0.2 to 0.9 and/or for intermediate DD, the limits of energy demand could be calculated applying a linear interpolation process.

For specific locations characterized by DD exceeding 3001, the limit of energy demand is determined by linear extrapolation, based on the values set for the E Climatic Zone, with reference to the number of the DD of the location of interest.

In this work have been considered four Italian cities (Table 3) representative of the entire peninsula and of different Climatic Zones: Milano (northern Italy, E Climatic Zone), Roma (Central Italy, D Climatic Zone), Napoli (Southern Italy, C Climatic Zone) and Messina (Southern Italy, B Climatic Zone);

Table 3 Four Italian cities and their climatic characteristics

Italian cities	Climatic Zone	DD	Heating Period
Milano	E	2404	15 October - 15 April
Roma	D	1415	1 November- 15 April
Napoli	C	1034	15 November - 31 March
Messina	B	707	1 December - 31 March

CLIMATIC DATA: METEONORM SOFTWARE

Meteonorm [42] makes possible to generate climatic data where measurements are not available. Originally, it was developed for the particular case of Switzerland but now is available for the whole world. It is based on well validated models and many databases of several tens of years. To generate the various climatic parameters, the software uses as input internal radiation values or real monthly mean values downloaded from the Internet. It also offers the possibility to import personal hourly or monthly data. In addition, it is also possible to specify the environment, such as for example, “open site”, “urban conditions”, etc.

Meteonorm permits to access a catalogue of meteorological data for solar applications and system design at any desiderated locations in the world. The database consists by a climatological dataset of 8.300 weather stations. Principal measured parameters are: monthly means of global radiation, temperature, humidity, precipitation, days with precipitation, wind speed and direction, sunshine duration. To generate a yearly time series it is possible to select different empirical data: data recorded between 1961–90 or between 2000–2009; for areas with low density of stations it is possible to use satellite data. From the monthly values (station data, interpolated data or imported data), Meteonorm calculates hourly values of all parameters using a stochastic model. The resulting time series correspond to “typical years”.

Usually, measurement data can only be used for locations close to the weather station; elsewhere, the data has to be interpolated among different stations. The sophisticated interpolation models inside Meteonorm allow a reliable calculation of solar radiation, temperature and additional parameters at any site in the world, selecting the weather stations and site. Furthermore, Meteonorm allows accessing to climate change forecasts by using the IPCC (Intergovernmental Panel on Climate Change) scenarios.

Meteonorm is widely internationally used; indeed in literature are used and are validated the databases of ASHRAE Fundamental Handbook, of NREL (National Renewable Energy Laboratory), of NOAA (National Oceanic Atmospheric Administration) and of Meteonorm [43]. To calculate the DD it is necessary to know the hourly trend of temperature of several years of the site that permits to generate the typical year. In this work, three different typical year were generated, based on:

- 1961-1990 time period
- 2000-2009 time period
- IPCC scenario.

The IPCC was established by the World Meteorological Organization (WMO) and by the United Nations Environment Programme (UNEP), to assess the scientific, technical and socio-economic information relevant for the understanding of the risk of human-induced climate change [44]. A set of scenarios was developed to represent the range of driving forces and emissions in the scenario literature to reflect current understanding and knowledge about underlying uncertainties. The scenarios cover a wide range of the main demographic, economic, and technological driving forces of GHG (Greenhouses Gases), sulphur emissions. Each scenario represents a specific quantitative interpretation of one of four storylines. All the scenarios based on the same storyline constitute a scenario “family. The set of scenarios consists of six scenario groups drawn from the four families: one group each in A2, B1, B2, and three groups within the A1 family, characterizing alternative developments of energy technologies: A1FI (fossil fuel intensive), A1B (balanced), and A1T (predominantly non-fossil fuel).

In this work, it was considered the B1 scenario at 2100. The IPCC B1 storyline and scenario family describes a convergent world with the same global population that peaks in mid-century and declines thereafter, with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies [44].

THE TYPICAL YEAR GENERATION

To better understand how the DD value is strongly dependent on the time series of yearly outdoor temperatures that are calculated by using monitored empirical values (or forecasted values for future scenarios), the authors calculated HDD for 3 different datasets and for 4 Italian cities.

Meteonorm was used to generate 3 different typical years for each cities (Milano, Roma, Napoli and Messina); the temperature profiles for Napoli are plotted in Figure 2.

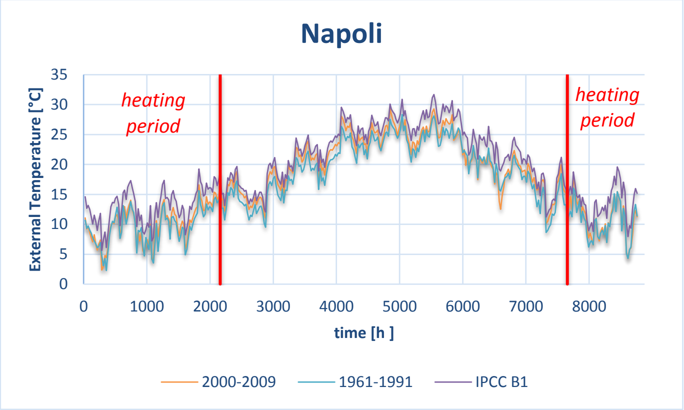

Figure 2 Temperature profile for each dataset in Napoli

The respective DD in Napoli, for heating period, are:

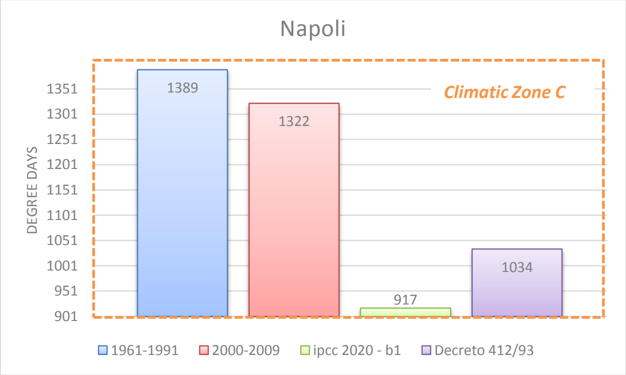

Figure 3 Degree days for each profile in Napoli

Comparison and results

Generally, for each cities, is it possible to see a drop of the DD value from 1°period (1961-1991) to 3° period (IPCC B1); the drop is caused by the simultaneous increase of the outside air temperature monitored firstly in 1961-1991 period, then in 2000-2009 period. Even the IPCC B1scenario foresees a rise in the outdoor temperatures due to the well-known phenomenon of global warming linked to the GHG emissions.

The value of DD dictated by the [36], is always lower than the value of extrapolated for the typical year based on the 1961-1991 period of measurement. Only for the city of Milano, the DD calculated with 2000-2009 measurement is lower than the value dictated by the Italian law.

Finally, the DD calculated, taking into account the IPCC B1 scenario is always lower than the value dictated by the Italian law. Table 4 collects, for each cities, a comparison among DD law values and DD calculated in the future scenario IPCC B1.

Table 4 Evaluation of DD in each cities

	DPR 412/93		IPCC B1		DD Reduction
	DD	Climatic Zone	DD	Climatic Zone	[%]
Milano	2404	E	2179	E	9.37
Roma	1415	D	1148	C	**18.86**
Napoli	1034	C	917	C	11.29
Messina	707	B	505	A	**28.50**

As it is possible to see in Table 4 the reduction of DD values, ranges from 9% to 28%, depending on latitude of the site. Furthermore, for Roma and Messina, the reduction of DD value leads to a variation of the Climatic Zone (toward a warmer zone).

Obviously, the change in Climatic Zone leads to different energy ratings for building: the $EP_{i,gl}$ energy demand required for heating will be lower. To better understand as the $EP_{i,gl}$ reference values could change, the following figures collect the comparison between the actual $EP_{i,gl}$ calculated with the DD law vales and the future hypothesized DD. In detail, Figures 4 and 5, for each cities, compare the current DD value calculated by the actual Italian low and the DD evaluated for future climate conditions. The first comparison is related to residential buildings; the second to other buildings.

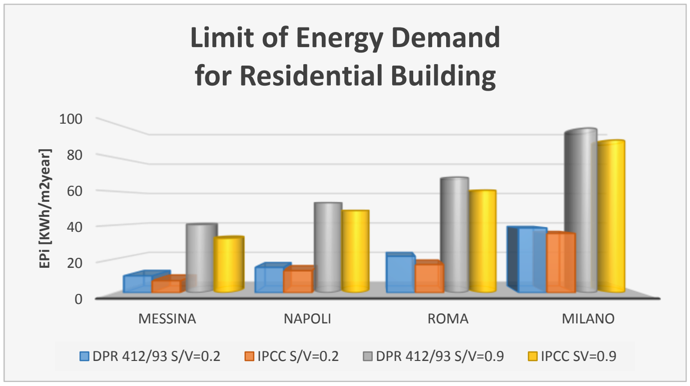

Figure 4 Comparison of different values of DD for residential building

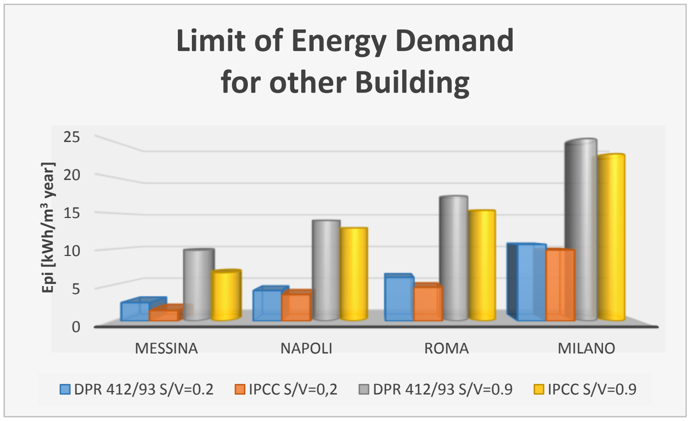

Figure 5 Comparison of different values of DD for other building

The following tables collect the results highlighting how the value of $EP_{i,limit}$ changes respect to those one calculated with the current law DD. Tables 5 and 6 refer to residential buildings for different S/V ratio.

Table 5 $EP_{i,limit}$ for residential building and S/V=0.2

S/V=0.2	Epi limit for residential building		
	DPR 412/93	IPCC	Reduction
	[kWh/m2 year]	[kWh/m2 year]	[%]
Messina	10.02	7.12	**28.98**
Napoli	15.07	13.07	13.23
Roma	21.55	16.70	22.51
Milano	38.31	35.11	8.36

Table 6 $EP_{i,limit}$ for residential building and S/V=0.9

S/V=0.9	Epi limit for Residential building		
	DPR 412/93	IPCC	Reduction
	[kWh/m2 year]	[kWh/m2 year]	[%]
Messina	40.25	32.15	**20.14**
Napoli	53.33	48.64	8.79
Roma	68.40	60.76	11.17
Milano	97.44	90.43	7.19

Generally, the greatest $EP_{i,gl}$ reduction is those one related to Messina, both for the residential and non-residential cases, with a reduction ranging from 20 to 40%.

Instead, the city of Milano is characterized by a lower change of $EP_{i,gl}$ (from 7% to 8%) than other cities. These results highlight how the variation of $EP_{i,gl}$ is higher in warmer Climatic Zones.

CONCLUSION

The value of DD for each considered location greatly influences the determination of the thermal energy demand for heating. The latter is the basis for sizing of HVAC plants in buildings. The higher the value of the DD, the higher will be the energy needs to maintain comfort conditions. Currently in Italy, the values of DD were derived from times series of outdoor temperature dating back to the 80s. These time series, nowadays are no longer reliable because the global climate change due to emissions of GHG.

After a review of DD extrapolation methods worldwide used, a deep analysis of the Italy procedure was carried out. The authors have used the software Meteonorm to calculate DD as function of more recent time series of temperatures, from 1961 to 1991 and from 2000 to 2009. Furthermore, DD was evaluated assuming valid the IPCC B1 scenario at 2100. The calculation of DD was extended to four main Italian cities and has allowed to quantify the variation due to climate changes. The results clearly show that new DD law values should be adopted. The adoption of new, more current, and more adherent to reality, values of DD should allow to lower the calculation of the thermal needs for heating. A more reliable planning of HVAC can reduce the size of the installations already in the design phase; at no additional costs, this procedure would significantly introduce raw materials and primary energy savings.

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