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The Role of Data and Program Structures on the Precision of Building Energy Performance Evaluation

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Abstract— Since design decisions play an important role in determining the energy performance of buildings, assessment tools are vital for the evaluation of the energy performance of buildings throughout the design process. Such tools should be precise and reliable, while complying with the local legislations and taking into account the local settings. It is also important for the user to understand the reliability/applicability of any tools to be used in the decision-making process. Since each of such tools uses different building codes, standards and data as well as legislative framework and/or rating special to the region of interest with different program structures and schedules, prominent differences are observed in the evaluation results. In this context, this paper investigates four different building energy performance evaluation tools in terms of program structures, which are highly acknowledged for their validity. It is aimed to map their program structures with similarities and differences so as to understand possible differences in the evaluation results.

Index Terms— Building Performance, Energy Performance, Evaluation Tool, Performance Assessment, Performance Evaluation Program, TS EN ISO 13790.

1 INTRODUCTION

Soft tools for the evaluation of building energy performance (BEP) have an important place both for the performance assessment and decision-making and optimization process [1]. Research studies have shown that the performance concept in a modern sense, used in engineering since the 1970s, has been gaining more attention, and building performance has become a guiding design principle in contemporary architecture [2, 3]. It is known that every design decision has a significant effect on the performance of a building; and the performance-based design approach is a compromise among the different systems, such as structure, acoustics, and energy, etc. Among these, energy performance is one of the most broadly debated issues in architecture [4, 5]. During the design process, the designer is required to verify and validate the design according to performance goals. This requires an integrated solution that is formulated with the help of different disciplines [6]. Technological advances in computational tools enable to analyse the performance of buildings before construc-tion starts [7]. As shown in Table 1, there are very few tools that can be used in early design phase, in which the most effective design decisions are taken. In fact, many tools are designed to be used to the end of the design when it becomes difficult to change the decisions.

TABLE 1
TOOLS USED DURING THE LIFE-CYCLE OF A BUILDING

Life cycle of a building					
Phases	Predesign	Design	Post-design	Construction	Operation & Maintenance
Step	Sketching Planning	Drawing Detailing Modelling	Rendering & animation Engineering design and evaluation	Construction management (CM)	Building-in-use retrofitting
Tools	Decision-making tools	Drawing & modelling tools	Rendering tools Structural design, Performance assessment tools	Construction, CM tools, cost estimation, facility Management, specification, Fabrication, BIM tools	Environmental analysis, labelling, certification, retrofitting, BIM, user satisfaction, evaluation tools

As a part of the performance-based design, BEP evaluation and optimization is a very broad subject that incorporates heat loss-gains, thermal comfort analysis, indoor air quality, HVAC equipment and systems, DHW supply, lighting and renewable energy, as well as energy require-ment/use evaluations, energy economics, environmental and atmospheric pollution, and certification; all of which must be addressed in compliance with building standards, codes and regulations. BEP evaluations can be carried out using very simple calculations, rating systems, or by complex performance simulation tools [8].

Rating systems constitute one of the first initiatives in BEP evaluation [9]. They were first developed for the evaluation of the environmental performance of a building in the 1990s [10]. They have also been supported by governments to encourage sustainability in the design of new buildings [11].

Today, these rating systems have become an integral part of performance-based design, and being frequently used to en-

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courage the design and labelling of high performance buildings. Some of the most popular rating systems around the world include BREEAM in the United Kingdom, LEED in the United States, HK-BEAM in China, Green Star in Aus-tralia, DGNB in Germany, CASBEE in Japan, etc.

Besides voluntary labelling systems, there are several policy and legislative activities making BEP evaluation mandatory [12, 13]. With the introduction of the Directive 2002/91/EC on the energy performance of buildings (EPBD) in 2002 [14], the EU Commission required countries to develop assessment tools and methods for the evaluation of performance and the certification of buildings. In this respect, the governments of many European nations have started developing their own national assessment tools and establishing private or semi-private organizations.

To date, building energy performance assessment guidelines and certification software have been developed by the related ministries or national institutions in Bulgaria, the United Kingdom, Finland, France, Ireland, Lithuania, Portugal and Southern Cyprus; by private organizations in Belgium and Holland; and through government/institutional/university collaborations in Italy and Romania [15]. Some examples of national assessment tools for the evaluation of the energy performance of buildings that have been developed by national institutions and/or organizations includes the Standard Assessment Procedure (SAP) in the United Kingdom, the Dwellings Energy Assessment Procedure (DEAP) in Ireland, and the Energy Performance Assessment for Non-Residential Buildings (EPA-NR) in Malta. In Turkey, BEP-TR, as a national tool for the evaluation of the energy performance of buildings, was launched by the Ministry of Environment in 2010, however since the validity and reliability of the tool has to date not been fully accepted, the reliability of the results of the evaluations is still in discussion.

Currently, more than 400 evaluation tools [16] have been developed around the world for the assessment of building performances. These tools carry out performance evaluations including whole building analysis, code compliance, equipment and systems, and specific applications, which are grouped based on the subjects and shown in Table 2. These tools are not only being used by the professionals for performance assessment, but also the out-puts of several programs are accepted both for the labelling and the energy performance certification of buildings as dis-cussed in the next sections.

Diversity of the tools provides the user with a broad range of option while helping to integrate computational tools into the architectural design process. Since the designer needs to evaluate and optimize the design and design decisions in any phase of the design, different tools are needed in different phases of the design. When selecting/using a performance evaluation tool, the designer/evaluator should consider the following subjects;

- Usability of the tool in any phase of the design
- Applicability of the database of tool to the local settings
- Compliance with the legislations
- The level of technical expertise to use the program
- Possibility of file transfers between the tools
- The precision range, reliability and the validity of the tool

Since each tool is developed by different groups for different regions and countries based on different building code and standards with different climatic conditions and diverse requirements, they handle the subject in different ways. It is evident that program data structure plays a crucial role in performance evaluation process and should be considered by the designer/evaluator very carefully. Although the differences between the tools are not clearly articulated, considerable differences in the results can be observed based on the legislations, calculation methods, databases, program defaults and assumptions used by the tools, which constitute the program data structure of a tool. This brings about complications in decision-making process and makes design optimization difficult. Hence the compatibility of these tools regarding the local settings, databases and legislations is extremely important in the decision making process.

TABLE 2
TOOLS USED FOR THE ENERGY PERFORMANCE ANALYSIS OF BUILDINGS

Subject	Analysis	Example tools
Whole building analysis	Energy simulation, load calculation, renewable energy, retrofit analysis, sustainability/green buildings	BSim (Denmark), DesignBuilder (UK), DOE-2 (US), Ecotect (UK), EnergyPlus (US), eQUEST (UK), HAP (US), TRNSYS (US)
Code and standards	Code compliance	Climawin 2005 (France), Czech National Calculation Tool (Czech Republic), DIN V 18599 (Germany), VentAir 62 (US)
Materials, components, equipment and systems	Envelope systems, HVAC equipment and systems, lighting systems	DAYSIM (Canada), LoopDA (US), MOIST (US), RHVAC (US)
Specific applications	Atmospheric pollution, energy economics, indoor air quality, water conservation	EMISS (US), Indoor Humidity Tools (US), METEONORM 6 (Switzerland), scSTREAM (Japan), Solar-5 (US), Virtualwind (Canada)

Contrary to many research studies [17, 18] dealing with the descriptive features and capabilities of performance evaluation tools, this paper focuses on their data structures in use. In this study, four different programs, namely DesignBuilder, EnAd, EnerCalc, and HAP, are chosen to exemplify the role of the data structure of the programs in decision making process based on the evaluations. The programs used in this study represent different dimensions in energy performance evaluations.

DesignBuilder and HAP are among the most widely used simulation programs around the world, while EnerCalc and

EnAd are calculation tools developed based on building standards that analyse the energy performance of buildings. DesignBuilder is used for BEP certification purposes in the UK and Ireland as well as whole building energy performance assessment, whereas HAP is among the most widely used programs in Turkey for system sizing and cooling load calculations. EnerCalc is developed like an educational version of DIN V 18599 tool to control the code compliance of buildings in Germany. EnAd, on the other hand, is developed as an alternative to the national assessment tool of Turkey, BEP-TR, for energy performance assessment of buildings. In the scope of this research paper, the features of the programs selected are illustrated to show their program structures, data input requirements and program outputs, as well as the calculation methods used. Such a study allows the identification of possible reasons for differences between the results of the different programs. Such a study will also help the designer to gain awareness in selecting/using an evaluation tool. If the user knows the framework, compatibility and convergence range of a program (to be) used, it becomes easier to improve the design decisions to the optimum.

2 General Structures of Energy Evaluation Programs

BEP evaluation tools in general, and selected programs in this study have similar structures as shown in Figure 1. Site selection part covers climatic data and the related legislations while form definition deals with the introduction of a building form and the material properties. Service systems in a building are based on the properties of heating, ventilation, air-conditioning (HVAC) system with a schedule of use. Accordingly, analysis and results include the energy requirement and/or use scales for a given period of time.

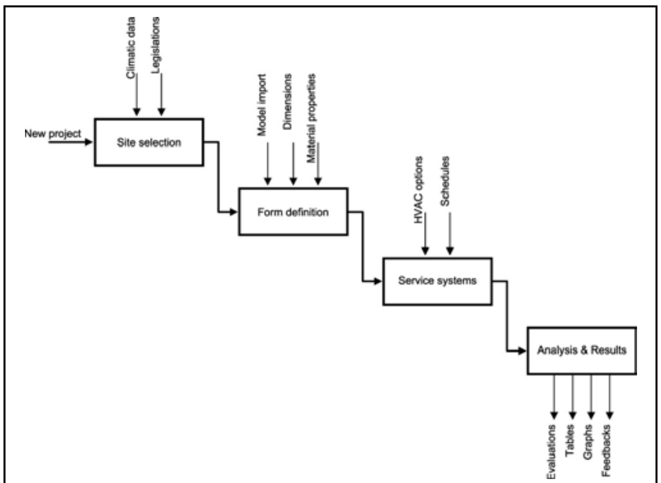

Fig. 1. General Structure of Building Energy Performance Assessment Tools

3 Evaluation Programs Selected

In this section, the four evaluation tools selected are briefly introduced. DesignBuilder, as a new program, has been developed based on EnergyPlus with a new interface. EnergyPlus is a simulation program, developed by the US Department of Energy (DOE) [19]. Hourly Analysis Program (HAP), developed by Carrier [20], is used for hourly building energy assessment and commercial HVAC sizing. Among these, EnerCalc, developed as a part of a PhD study [21], is based on German standard series of DIN V 18599 [22] for the energy efficiency of buildings concerning national calculation methods. EnerCalc, a data sheet-based calculation tool, is a simplified version of the DIN V 18599 tool [23]. EnAd, also developed as a part of a PhD study [24], is a decision support tool for architectural design process. Similar to EnerCalc, EnAd is developed compatible with their own national rules and legislation, including EPBD, TS EN ISO 13790 [25] and Turkish BEP Regulation (2008) [26] and related documents, and treats legislation as the design goal and the constraints.

Common features and differences of the four programs selected are illustrated in Figure 2. In all these programs, the input of the location is the first step in the evaluation process; however, one of the major differences between the programs is the use of different climatic data. EnAd and EnerCalc use national climatic data, while the others use the international weather data approved by ASHRAE. Another difference can be noted in the code compliance. Since these programs are developed by different groups/countries, they are required to comply with different standards and legislations. EnAd is based on Turkish legislation; EnerCalc is compatible with German standards; HAP is based on ASHRAE standards; while DesignBuilder is compatible with Part-L of the UK and Ireland Building Regulations, as well as ASHRAE standards.

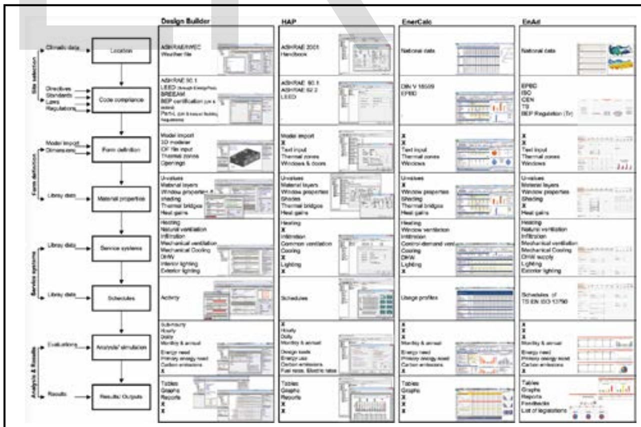

Fig. 2. Program Structures of the Selected Evaluation Tools

As seen in Figure 2, all these programs require defining building form as thermal zones in text-based data input, except DesignBuilder requiring 3D model. In all programs, properties of building envelope are determined by U-values, material layers, window properties, shading, thermal bridges and infiltration while EnAd does not include thermal bridges in the evaluations. And EnerCalc does not provide a material library or material layers for the building envelope.

Figure 2 also shows that all these programs evaluate all service systems used in a building, some of which are not available in HAP including natural ventilation and DHW use. Regarding schedules, EnAd uses the schedules defined by TS

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EN ISO 13790 and BEP Regulation as default while allowing the user to define duration of use for the service systems. Other programs provide default schedules allowing changes to be made.

As can be seen in Figure 2, each of the four tools performs performance analyses for different time intervals. All four programs make monthly and annual evaluations, while the simulation tools, DesignBuilder and HAP, allow for hourly and daily analysis as well. All of the programs present the evaluation results in graphs and tables as well as reports. Besides these, EnAd also provides feedback to the user to assist in improving design decisions, and informs the user of the related legislations to be covered during the design process.

4 Common Features of the Programs

The common features of the programs are presented in Table 3. As seen in Table 1, EnAd is used for the evaluation of residential and office buildings, while HAP and EnerCalc are developed for commercial buildings. Design Builder can be used for residential buildings as well. Two of the selected programs, HAP and Design Builder, are commercial programs requiring high license fees, while EnerCalc is a freeware program, intended to be used for educational purposes. Similar to EnAd, EnerCalc is developed based on legislation, while HAP and DesignBuilder are simulation programs. EnAd and EnerCalc can be used by any user, whereas HAP and Design Builder require an advanced technical background on the subject. EnAd, EnerCalc and HAP are text-based tools, while DesignBuilder requires a 3D model. Finally, the program language of EnerCalc is German, while the others are in English.

5 Differences in Program Structures

In order to investigate the program structures of the assessment tools more systematically, it is beneficial to group the evaluation steps under four main headings: (1) site selection, including climatic data and code compliance, (2) form definition with material properties, (3) service systems and schedules, and (4) evaluations and the results of the programs, which are explained in the following sections.

TABLE 3
Common Features of the Selected Programs

	Design Builder	HAP	EnerCalc	EnAd
Area of use	Commercial and residential buildings	Commercial buildings	Commercial buildings	Residential & Office buildings
Availability	Commercial	Commercial	Freeware Educational	Freeware
Primary goal of the tool	Simulation, evaluation	Simulation, evaluation	Evaluation	Evaluation and feedback for design decisions
User profile	Professionals	Professionals	Students and professionals	Any user
Level of expertise to use program	Middle to upper	Middle to upper	Novice to Middle	Novice
Program Language	English	English	German	English
Data Input	Model-based[1]	Text-based Model based[2]	Text-based[3]	Text-based[3]

[1] Images and 2D drawings in dxf file format may be imported for dimension use, while a 3D model should be created in the DB medium, or BIM models may be imported in the gbXML format
[2] Only BIM models in the gbXML format can be imported.
[3] No drawing or modeling file can be accepted for data input.

5.1 Site Selection

Climatic data is of paramount importance in energy performance evaluations. Since it includes the data about the location such as outside temperatures and solar radiation values, the database plays a determinant role in calculating heating and cooling periods and solar gains of a building. Table 4 provides the input data required by each program for defining the location of a building. All of the four programs selected uses different weather databases based on national and/or international data sources. Difficulty in editing hourly weather data files makes it almost impossible to modify these files. Hence the use of different climatic databases is one of the major reasons for deviations in the analysis results. Code compliance of the tools represents another source of deviation in the results. Since each tool is developed for different regions and countries, they cover different legislations and standards as well as different rating and certification systems.

5.2 Form Definition

The definition of building form and the properties of the

TABLE 4
Input Data on the Location of a Building

	Design Builder	HAP	EnerCalc	EnAd
Climatic data	ASHRAE/IWEC (P)[1]	ASHRAE 2001 Handbook (P)	National data (E)[2]	National data (E)[3]
Code compliance	ASHRAE Part-L Building regulations	ASHRAE	DIN V 18599 EPBD	EPBD TS EN ISO 13790 Turkish BEP Regulation
Certification	LEED BREEAM The UK BEP certification	LEED	German BEP certification	Turkish BEP certification

E: Editable P: Partly editable
[1] Although international weather data used by the simulation tools claims to be editable, the files have hourly average data for a ten-year period for each city, making it almost impossible to modify these files.
[2] The program has weather data for one general and 16 climatic regions in Germany. If required, weather data can be introduced to the program for different cities and countries.
[3] The program has weather data for 81 cities in Turkey. If required, new weather data can be introduced to the program for different cities and countries.

building envelope is the most important data input step for each program (Table 5).

ISSN 2229-5518

TABLE 5
INPUTS FOR FORM DEFINITION AND MATERIAL ASSIGNMENT

	Design Builder	HAP	EnerCalc	EnAd
Introduction of the geometry				
2D-3D model import				
Embedded CAD	Both (E)	Only 3D (E)	NA	NA
Text-based data[1]				
Net area in the computation	✓ (E)	NA	NA	NA
Net volume in the	NA	✓ (E)	✓ (E)	✓ (E)
computation	Internal dimensions of the	Manual input (A_n)	Manual input (A_n)	Average (V_{brut}*0,32)
#/density of occupants	model			
	Internal dimensions of the	Calculated (A_n *h_{int})	Calculated (A_n *h_{int})	Average (V_{brut}* 0,8)
	model			
	people/m²	# of people or m²/people	x	# of people
Zoning	Single or multi-zone[2]	Single or multi-zone	Single or multi-zone[3]	Single zone
(thermal zone)				
Construction				
Construction type	✓ (3) (E)	✓ (3) (E)	✓ (3) (O)	✓ (3) (E)
Light		Building weight (146.5 kg/m²)	S. heat capacity	S. heat capacity (110,000 (J/K)*
		Building weight (341.8 kg/m²)	(50 Wh/(m²K)* A_f)	A_f)
Medium		Building weight (634.7 kg/m²)	S. heat capacity	S. heat capacity (165,000 (J/K)*
		✓ (100+) (E)[4]	(90 Wh/(m²K)* A_f)	A_f)
Heavy		✓ (100+) (E)	S. heat capacity	S. heat capacity (260,000 (J/K)*
		✓ (4) (E)	(130 Wh/(m²K)* A_f)	A_f)
Material library	✓ (100+) (E)[4]		x (U-values)[5]	✓ (100+) (E)[6]
Windows	✓ (100+) (E)		✓ (13) (O)	✓ (14) (E)
Window frames	✓ (7) (E)		✓ (8) (O)	✓ (8) (O)
Shading				
from external objects	✓ (E)	✓ (E)	✓ (O)	✓ (O)
Window shading			$F_s = \min (F_h; F_o; F_f)$[7]	$F_s = F_h . F_o . F_f$[7]
	✓ (O)	✓ (E)	✓ (O)	NA
Thermal bridges	Default (O)[8]	✓ (E)	DIN (O)	NA
Heat losses			$Q_{ht} = Q_{tr} + Q_{ve} + Q_{I,loss} + Q_S$[9]	$Q_{ht} = Q_{tr} + Q_{ve}$
Solar gains	✓ (U)	✓ (E)	✓ (U)	✓ (U)
			-	$Q_{sol} = (F_{sh,ob} . A_{sol} . I_{sol} - F_r . \Phi_r)\ t$
			$Q_{S,tr} = F_F\ A\ g_{eff}\ I_S\ t$ (transparent)	$A_{sol,gl} = F_{sh,gl} . g_{gl} . A_{win} . (1 - F_F)$
			$g_{eff} = F_S\ F_w\ F_V\ g_\perp$	$A_{sol,op} = \alpha_{sol,em} . R_{se} . U_{op} . A_{op}$
			$Q_{S,op} = R_{se}\ U\ A\ (\alpha\ I_S - F_f\ h_r\ \Delta\theta_{er})\ t$	$\Phi_r = R_{se} . U_{op} . A_{op} . h_r . \Delta\theta_{er}$
			for $\alpha\ I_S > F_f\ h_r\ \Delta\theta_{er}$ (heat gain)	
			(opaque)	
			$Q_{S,op} = R_{se}\ U\ A\ (F_f\ h_r\ \Delta\theta_{er} - \alpha\ I_S)\ t$	
			for $\alpha\ I_S < F_f\ h_r\ \Delta\theta_{er}$ (heat loss)	
			(opaque)[10]	
Internal gains	Default	ASHRAE	Default	TS, ASHRAE
Average	NA	NA	NA	✓ (E)
Living+Kitchen	NA	NA	NA	✓ (U)
Other spaces	NA	NA	NA	✓ (U)
Occupancy	✓ (E)	✓ (E)	✓ (E)	✓ (U)
Office equip.	✓ (E)	✓ (E)	✓ (U)	✓ (U)
Catering	✓ (E)	NA	NA	NA
Lighting	✓ (U)	✓ (U)	✓ (U)	✓ (U)
DHW use	NA	NA	✓ (U)	✓ (U)
HVAC system	NA	NA	✓ (U)	NA
Other	✓ (E)	✓ (E)	✓ (U)	NA
			$Q_I = Q_{I,p} + Q_{I,L} + Q_{I,fac} + Q_{I,goods}$	$Q_{int} = \Phi_{int,mn}\ t$
			$+ Q_{I,h}$[11]	$\Phi_{int} = \Phi_{int,sen,D} + \Phi_{int,sen,M} +$
				$\Phi_{int,App,lat} + \Phi_{int,Occ,lat} + \Phi_{int,W} + \Phi_{int,lg}$
				[12]

E: Editable U: Un-editable P: Partly editable O: Optional NA: Not Applicable

[1] *Size, dimensions and number of components introduced to the given cells*

[2] *All rooms should be modeled with an activity assignment. Each zone is introduced as conditioned or unconditioned; occupied or unoccupied; and/or include in thermal zone calculations or not.*

[3] *A single zone assessment is performed for residential buildings. For non-residential buildings, after the introduction of the building dimensions, the sizes and schedule of each zone are introduced one by one.*

[4] *The program features a rich material library, and allows the addition of new items, both for default values and component layers.*

[5] *The program only provides three types of construction (light, middle and heavy construction). The U-values for surfaces (wall, floor and ceiling) are introduced by the user. There are limited types of glass and frame.*

[6] *The program gives special importance to the building envelope, and thus it has a very rich material list for component layers, as well as default values, and allows the introduction of new materials.*

[7] *EnerCalc takes minimum shading from the horizon, overhang or fins; while EnAd takes a multiplication of all factors.*

[8] *Thermal bridges can be taken into account if the user checks the related box. Thermal bridge calculations are handled by the program, that is, the value cannot be changed by the user.*

[9] *Besides heat flow due to heat transfer and ventilation, it includes heat flow due to internal heat losses and radiative heat transfer*

[10] *Although the formulas seem to be different, they are almost the same.*

[11] *Internal heat gains from occupants, lighting, electrical equipment, goods/materials, heating/cooling system. Instead of calculation, all values are taken from DIN 18599-10 usage profiles lists.*

[12] *Sensible and lateral gains from occupants and electrical equipment, DHW use, lighting.*

This step covers a wide range of data, starting from the introduction of the building form, zoning, construction type, shading and thermal bridges, to heat losses and heat gains. This is presented in Table 5, which shows the availability of each option in each program, as well as the way the data is handled by the programs, such as editable, un-editable, partly editable, optional and not applicable. Table 5 also shows the default values and the formula used by the programs, if available, to show the differences between the calculations and methods used by the programs.

As seen in Table 5, the introduction of the building form is handled in different ways in the programs, some of which work on text-based input while some others require 3D model. Furthermore, each tool makes different assumptions for the net floor area and volume included in computation. The number of people in a building and the conditioned net area and volume values included in the computations affect both internal gains and losses, and energy requirement values per building and per area. While minor differences among the programs are observed in the calculations, the discrepancy gets larger as the project gets bigger.

Once the building form is introduced, the properties of the building envelope are determined. All programs feature an editable material library, while EnerCalc has neither a library nor material layers. As shown in Table 5, all four programs define three types of construction, light, medium and heavy, however the default values for each type are different in each program. Construction type values can change according to each country since construction types depend strongly on local traditions. This value affects the time constant of the building, which is used to determine the length of seasons and/or hours required for the heating and cooling of a building. In this regard, the differences between construction types results in discrepancies in the evaluations, which should also be taken into account. Considering the window properties, all programs have editable options for windows and window frames, except EnerCalc, which does not allow changes in the properties.

All programs take solar gains into account in their evaluations; however, the method/formula is not known for all. Furthermore, since the programs use different climatic data, solar gain calculations differ between the programs and lead to different results. Another important source of heat in the evaluations are internal heat gains, which are also taken into account in very different ways by the individual tools. Heat gains from solar and internal heat sources are not fully controlled by the users, and thus result in differences in results. Other differences between the programs resulting in deviations include the effects of shading and thermal bridges. These matters should also be taken into consideration when evaluating the results.

5.3 Service Systems Used in Buildings

The third group of data required by the programs for the evaluations is related to the service systems used in the buildings, including heating, cooling, ventilation, domestic hot water and lighting. As in the form definition, service systems are introduced into each program in different ways. Table 6 summarizes the service systems and their means of introduction into each tool with the input data required by the programs, options, default values and formulas.

As can be seen in Table 6, all four tools require a determination of the properties of service systems, based on the type of equipment, the fuel type and its energy efficiency, as well as the set-point temperatures and primary energy conversion. They provide several options and/or editable library, depending on the scope of each program, either providing only a limited number of standard equipment or requiring a very detailed information about the system. Each different input data between the programs brings about differences in the results. All four tools have their own coefficients for primary energy conversion, which are uneditable. Although the conversion coefficients for natural gas seem to be very close to each other in all programs, those for electricity are very different, which also leads to differences in the results.

Buildings can be ventilated naturally or by mechanical means. All four tools evaluate the natural ventilation, mechanical ventilation and infiltration in buildings; however, HAP does not cover natural ventilation directly. EnAd provides for two types of natural ventilation: minimum ventilation and natural ventilation, for which the airflow rate is determined according to the shielding of the building considered. For infiltration, the tool determines infiltration based on the airtightness of the building envelope, for which the default values of the BEP Regulation are adopted. EnerCalc, on the other hand, use default values for the determination of ventilation type, the control type and the heat recovery efficiency of the system. HAP requires to define ventilation system components, including airflow control, ventilation sizing method, minimum airflow, damper leak rate, minimum and maximum CO2 differential rates, etc. Similar to HAP, DesignBuilder also requires very detailed data inputs including the set point temperatures, outside air definition method, outside airflow rate, schedule, minimum fresh air per person and mechanical ventilation per area. Since minimum, maximum or optimum values for these requirements are not provided by the program, such inputs can be complex for the new low-end users.

All four tools consider artificial interior lighting, while exterior lighting is only taken into account in EnAd and DesignBuilder. In all programs, the energy need for interior lighting is calculated according to the luminaire type, lamp type, the radiant fraction value for evaluation coefficients as well as lighting power, as either W/m2 or lux. Although each tool requires different types of data, as shown in Table 6, the interior lighting calculations are almost the same for all tools.

HVAC systems work according to schedules defined by the user or by the default values of the tools. Schedules can be adjusted to desired hours of a day, months and year. EnAd uses the coefficients defined by TS EN ISO 13790 and the BEP Regulation while it requires hourly schedules for office buildings.

TABLE 6
INPUTS FOR SERVICE SYSTEMS

	Design Builder	HAP	EnerCalc	EnAd
Space heating				
Heater type	Default (E)	Default (E)	✓ (8) (O)	✓ (75) (O)
Fuel type	✓ (7) (O)	✓ (4) (O)	NA	NA
Heating set temp.	18°C (E)	21°C (E)	20°C (E)	20°C (E)
Programmer	NA	✓	✓ (3) (O)	✓ (3) (O)
Equipment efficiency	1 (E)	Default (E)	Default (U)	Default (E)
Pr. En. Conv.				
	Default (U)	Default (U)	Default (U)	Default (E)
			$Q_{H,nd}=Q_{H,ht}-\eta_{H,gn}Q_{H,gn}$	$Q_{H,nd}=Q_{H,ht}-\eta_{H,gn}Q_{H,gn}$
			$\eta=(1-\gamma^{a})/(1-\gamma^{a+1})$ if $\gamma\neq1$ [1]	$\eta=(1-\gamma^{a})/(1-\gamma^{a+1})$ if $\gamma>0$
			$\eta=a/(a+1)$ if $\gamma=1$	$\eta=a/(a+1)$ if $\gamma=1$
				$\eta=1/\gamma_{H}$ if $\gamma<0$
Space cooling				
Conditioner	NA	✓ (E)	✓ (7) (O)	✓ (3) (O)
Fuel type	✓ (7) (O)	✓ (4) (O)	NA	NA
Cooling set temp.	24°C (E)	25°C (E)	26°C (E)	26°C (E)
Min. set point control	NA	Default (E)	NA	NA
Efficiency class				
CoP	NA	NA	NA	✓ (10) (O)
Pr. En. Conv.	1 (E)	✓ (E)	Default (U)	Default (U)
	Default (U)	Default (U)	Default (U)	Default (U)
			$Q_{C,nd}=Q_{C,gn}(1-\eta_{C,ls})$ [2]	$Q_{C,nd}=Q_{C,gn}-\eta_{C,ls}Q_{C,ht}$
DHW supply	International	NA	to area or person	TS
Water heater	NA		NA	✓ (7) (O)
Fuel type	✓ (7) (O)		NA	NA
Use water temp	65°C (E)		NA	50°C (E)
Supply water t.	10°C (E)		NA	10°C (E)
Daily usage	l/m² d (E)		Wh/m²d kWh/p d (U)	l/p d kWh/p d kWh/m² d (E)
CoP	1 (E)		1 (U)	Default (E)
Pr. En. Conv.	3,167 (U)		2,60 (U)	2,36 (U)
			$Q_{w,b}=q_{w,b}*d_{mth}/365*d_{nutz}$ *reference [3]	$Q_{w,b}=p.c.V_{w}.(\theta_{w,m}-\theta_{k})t$
Ventilation				
Natural Vent.	✓ (E)	NA	✓ (O)	✓ (O)
Mechanical Vent.	✓ (E)	✓ (E)	✓ (O)	✓ (E)
Infiltration	✓ (E)	✓ (E)	✓ (O)	✓ (E)
			$Q_{ve}=\Sigma H_{ve}(\theta_{i}-\theta_{e})t$	$Q_{ve}=\Sigma H_{ve}(\theta_{i}-\theta_{e})t$
			$H_{ve}=H_{ve,win}+H_{ve,mech}$ $+H_{ve,inf}+H_{ve,U}$	$H_{ve}=H_{ve,win}+H_{ve,mech}$ $+H_{ve,inf}+H_{ve,U}$
			$H_{ve}=p.c.V.n$	$H_{ve}=p.c.V.n$
Interior lighting				
Luminaire type	✓ (5) (O)	✓ (3) (O)	NA	NA
Lamp type	NA	NA	✓ (13) (O)	✓ (3) (O)
Radiant fraction	✓ (E)	✓ (E)	according to lamp type (U)	according to lamp type (U)
Lighting /Power	W/m² (E)	W/m² (E)	lux	W; W/m² (E)
			$Q_{l}=p.[A_{TL}(t_{eff,day,TL}+t_{eff,night,TL})+A_{KTL}(t_{eff,day,KTL}+t_{eff,night,KTL})]$ [4]	$W_{year}=[(52*5*P_{hi})+((52*2+1)*P_{hs})]/1000$ [5]
Exterior lighting	✓	NA	NA	✓
Schedules				
Type	Default (E)	Default (E)	Default (DIN)	Default (ISO; BEP Regulation)
Time step	24 hours (E)	24 hours (E)	24 hours (E)	24 hours (P)

E: Editable U: Un-editable P: Partly editable O: Optional NA: Not Applicable

[1] Different from ISO, DIN standards accept two types of gain-loss ratio.

[2] In cooling energy need computations, DIN standards only consider heat gains and assume that there is no heat loss.

[3] DHW need is calculated depending on daily and monthly coefficients and per unit/person use profiles.

[4] It considers areas with/out daylight and with day and night usage patterns.

[5] It computes the need for artificial lighting depending on the number and power of lamps and weekdays and weekend coefficients.

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EnerCalc requires the definition of usage profiles for each zone, including information about the service and operating hours, lighting, indoor air, heat gains, set point temperatures for heating and cooling, specific geometries and mechanical ventilation options. HAP uses three types of schedule, which are utility rate time-of-day, fan/thermostat and fractional (occupancy, lighting, equipment, ventilation airflow, electric, etc.). DesignBuilder, on the other hand, requires defining very detailed 'activity' templates for each zone, which include occupancy, metabolic rates, DHW consumption rate, minimum fresh air requirements, illuminance requirements, and electrical equipment information for heat gains.

5.4 Calculation Methods used by the Programs

Once the design decisions related to the site, building form and properties of the building envelope are made, and the service systems and their schedules are set, all of the four programs calculate the energy requirements for the building and evaluate its energy use for various time intervals, such as sub-hourly, hourly, daily, monthly and annual. As can be seen in Table 7, all programs make evaluations on a monthly and annual basis, while DesignBuilder and HAP, the simulation tools, also perform hourly and daily evaluations. Outputs are presented in the form of tables, graphs and reports. Furthermore, EnAd provides feedback to achieve higher performances, while also showing the legislation to be covered during the design process. The major difference between the four programs can be found in their method of calculation.

TABLE 7
EVALUATIONS AND RESULTS FOR THE SELECTED TOOLS

	Design Builder	HAP	EnerCalc	EnAd
Calculation method	Heat balance model of EnergyPlus	ASHRAE-endorsed transfer function method	Monthly calculation method of DIN EN ISO 13790	Monthly calculation method of TS EN ISO 13790
Evaluation				
Energy requirement	kWh & kWh/m²	kWh	kWh/m²	kWh & kWh/m²
Energy use	kWh & kWh/m²	kWh	NA	kWh & kWh/m²
Primary energy	kWh (just total)	kWh	kWh/m²	kWh & kWh/m²
Energy costs	NA	$ (E)	NA	NA
Sub-hourly	✓	NA	NA	NA
Hourly	✓	✓	NA	NA
Daily	✓	✓	NA	NA
Monthly & annual	✓	✓	✓	✓
Outputs Exports				
Graphs	✓ (jpeg)	✓ (rtf)	✓ (xlsx)	✓ (xlsx)
Tables	✓ (csv)	✓ (rtf)	✓ (xlsx)	✓ (xlsx)
Report	✓ (html)	✓ (rtf)	NA	✓ (xlsx)
Feedbacks & Information	NA	NA	Required thickness of insulation material Energy that can be covered by PV systems	Feedback for improvements Lists of legislation regarding each subject

The main reason for the variations in the data inputs and outputs is the different calculation methods employed by the individual programs. EnAd uses the monthly calculation method of TS EN ISO 13790, using the daily and monthly correlation coefficients determined by the BEP Regulation and TS EN ISO 13790. Similar to EnAd, EnerCalc uses the monthly calculation method of DIN EN ISO 13790, but the tool uses the daily use patterns and schedules of DIN V 18599 with monthly correlation coefficients. DesignBuilder, on the other hand, uses the heat balance model of EnergyPlus, considering heat and mass balance calculations. HAP uses the ASHRAE-endorsed transfer function method for load calculations.

EnAd and EnerCalc, both based on EN ISO 13790, consider the building as one thermal zone and evaluate the building envelope as a whole, while DesignBuilder and HAP calculate each zone separately. In line with EN ISO 13790, EnAd and EnerCalc consider heat gains and losses to be present throughout the year, whereas DesignBuilder and HAP disregard heat gains in heating load calculations. EnAd and EnerCalc use the correlation coefficients determined in the TS and DIN standards and gain-loss utilization factors to control the results; while DesignBuilder and HAP make simulations based on the maximum number of days specified for the heating and cooling periods until the temperatures in each zone are converged.

The differences between the calculation and evaluation methods employed in the programs do not necessarily result in different assessments of energy performance in terms of grading. Since each tool has a different program structure and adopts a different calculation method, differences can be observed both in the databases, such as in the climatic data and the material library, and in the input data, such as type and quantity of input data, and the units of measurement used in the programs. Even though the quantitative values and the calculation methods differ, since they all result in an assessment for energy performance, the final assessment grades can be very alike. This is explored through a reference case in the following section.

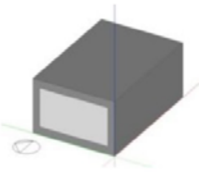
6 DIFFERENCES OBSERVED IN THE RESULTS OF THE PROGRAMS: A REFERENCE CASE

6.1 Description of the Case

In order to compare the data input and output steps between different programs, a very basic example with evaluation inputs and output is selected as a case, which is the reference case given in TS EN ISO 13790. The case is assessed by all four programs, and the results of each are compared to identify differences. TS EN ISO 13790 provides the thermal properties and calculation results for a single office room in Paris, which has a floor area of about 20m2 and a ceiling height of 2.8m. The office has only one exterior wall containing a window facing west, while other walls, floor and ceiling are accepted to be adjacent to conditioned zones. The room is heated, cooled and mechanically ventilated for ten hours on weekdays. The case assumes a 20 W/m2 internal gain for ten hours on weekdays, and solar gains according to the weather data provided by the standard. The case is evaluated according to the monthly and annual method of the standard. The general features of the test case are presented in Table 8, while the input data entered for each tool is given in Table 9.

TABLE 8
GENERAL FEATURES OF THE REFERENCE CASE

Case	Single office room
Location	Paris, France
Floor area	19.80 m2
Floor height	2.8m
Exposed surface	West façade
Window/wall ratio	2.27 (7 x 3.08)
Construction type	Heavy
Internal gains	20 W/m2
Heating	08:00–18:00 weekdays
Cooling	08:00–18:00 weekdays
Natural Ventilation	x
Mechanical Ventilation	08:00–18:00 weekdays
Infiltration	x
DHW use	x
Lighting	x



6.2 Evaluation of the Case

The reference case is assessed by each tool individually using the input data given in Table 9 (next page). The internal dimensions are considered as a single zone with construction properties as determined in the standard. No shading or thermal bridges are taken into account. Solar gains are considered according to the climatic data, while occupants, office equipment, DHW use, lighting and their internal heat gains are all disregarded, with internal heat gains assumed to be 20 W/m2 on average. The office is heated, cooled and mechanically ventilated for ten hours on weekdays throughout the year. The set point temperature for heating is accepted as 20°C, while that for cooling is 26°C. Although the standard gives no information about the types of heater or air conditioner and their coefficient of performance (CoP) and fuel types, they were defined and used by all tools to complete the evaluation. As can be seen in Table 9, all these properties are introduced to each program in similar ways, although several differences are observed among the programs, particularly in climatic data.

In the calculations, the climatic data for Paris given by TS EN ISO 13790 (2008) is introduced into EnAd and EnerCalc, while DesignBuilder uses ASHRAE/IWEC and HAP uses ASHRAE 2001 Handbook weather data file for Paris [27]; however the monthly average temperatures and solar radiation data given by TS EN ISO 13790 are different from that of ASHRAE/IWEC, which are presented in Table 10.

As can be seen in Table 10, the monthly and annual average values used by the standard and the simulation tools differ by 10% for outside temperatures, and by 15% for solar radiation data. This may lead to discrepancies in the calculations of both the solar gains due to the differences in the solar radiation data, and the energy requirement for heating and cooling due to the temperature differences, as well as the calculation method used by the programs.

Another difference in input data can be found in the definition of building form in the tools. Each tool calculates the net area and volume in different ways. The values of the net area and interior height of the office are given in EnerCalc and HAP. In EnAd, since the tool works with external dimensions, as required by the standards, larger dimensions are defined to obtain the values determined for the net area and volume. Similarly, in DesignBuilder, a 3D model is created using larger dimensions to obtain the same net area and volume.

TABLE 10
WEATHER DATA FOR PARIS USED BY TS EN ISO 13790 AND ASHRAE/IWEC

	TS EN ISO 13790		ASHRAE/IWEC	
	Monthly average outside temperature °C	Solar radiation (west) W/m2	Outside temperature °C	Solar radiation (west) (estimated)* W/m2
January	3.2	20	3.9	16
February	4.8	37	4.2	28
March	6.3	85	7	44
April	7.8	82	10	66
May	13	99	14.3	84
June	15.4	117	16.8	101
July	18.3	125	19.4	103
August	17	92	19.7	98
September	14.9	68	15.7	66
October	10.1	44	11.3	42
November	5.4	21	6.4	23
December	4.2	17	4.5	12
Average	10	67.3	11.1	56.9

** Monthly average solar radiation data is not provided directly in the IWEC file, which is estimated according to the solar gains produced by DesignBuilder.*

Other differences in input data are observed in EnerCalc due to its limitations. For instance, the value for heavy construction in EnerCalc cannot be changed, being set at 130 Wh/m2K, while this figure is 355000 J/m2K both in the standard and in the other programs. Since the tool does not provide an option for material layers, only the U-value of the western façade is given, as 0.493 W/m2K. Additionally, since the tool does not allow the window properties to be changed, a double glazed window without frame, which has the closest properties to that of the test case, is selected. Internal gains are introduced as 120 Wh/m2d according to the DIN V 18599-10 use profile lists. Since there is no schedule for internal gains, it is not known whether the tool considers this value as ten hours or a whole day and/or week. Furthermore, EnerCalc assumes that there should be infiltration of at least 0.6 ac/h at 50 Pascals, according to the passive house standard, and so this lowest value is used for the test case.

TABLE 9
INPUT DATA FOR THE REFERENCE CASE

		Design Builder	HAP	EnerCalc	EnAd
Location	Climatic data	Paris (ASHRAE/IWEC)	Paris (ASHRAE 2001 Handbook)	Paris data from TS EN ISO 13790	Paris data from TS EN ISO 13790
	Code compliance	ASHRAE	ASHRAE	DIN V 18599	TS EN ISO 13790 Turkish BEP Regulation
Form definition	Introduction of the geometry				
	Internal dimensions				
	Net area	5.5m * 3.6m * 2.8m	5.5m * 3.6m * 2.8m	5.5m * 3.6m * 2.8m	5.5m * 3.6m * 2.8m
	Net volume	19.8 m^2	19.8 m^2	19.8 m^2	19.8 m^2
	# of occupants	55.4 m^3	55.4 m^3	55.4 m^3	55.4 m^3
		-	-	x	-
	Zoning (thermal zone)	Single zone	Single zone	Single zone	Single zone
	Construction				
	Construction type	Heavy	Heavy	Heavy	Heavy
	Material library	Reference materials[2]	Reference materials	x	Reference materials
	U-value (wall)	0.493 W/m^2K	0.493 W/m^2K	0.493 W/m^2K	0.493 W/m^2K
	Windows	DG (U: 2.375; gl: 0.20)	DG (U: 2.375; gl: 0.20)	DG (U: 0.84; gl: 0.37)[1]	DG (U: 2.375; gl: 0.20)
	Window frames	No frame	No frame	No frame	No frame
	Shading				
	from external objects	No shading	No shading	No shading	No shading
	Window shading	No shading	No shading	No shading	x
	Thermal bridges	No thermal bridge	No thermal bridge	With thermal bridge[2]	x
	Solar gains	Default	Default	Default	Default
	Internal gains				
	Average internal gain	20 W/m^2	20 W/m^2	120 Wh/m^2d	20 W/m^2
	Living+Kitchen	x	x	x	-
	Other spaces	x	x	x	-
	Occupancy	-	-	-	-
	Office equip.	-	-	-	-
	Catering	-	x	x	x
	Lighting	-	-	-	-
	DHW use	-	x	-	-
	HVAC system	x	x	-	x
	Other	-	-	-	x
Service systems	Space heating				
	Heater type	Boiler	Boiler	Boiler	Boiler
	Fuel type	Natural gas	Natural gas	Natural gas	Natural gas
	Heating set temp.	20°C	20°C	20°C	20°C
	Setback temp.	18°C	18°C	18°C	x
	Programmer	x	-	-	-
	Equipment efficiency	0.74	0.74	0.63[3]	0.74
	Pr. En. Conv.	1.084	1	1.10	1
	Energy need	454 kWh	715 kWh	525 kWh	567 kWh
	Primary energy need	613 kWh	966 kWh	837 kWh	766 kWh
	Space cooling				
	Conditioner	Default	Chiller	Air cooled compressor. improved	Air cond. except single/double duct
	Fuel type	Electricity	Electricity	Electricity	Electricity
	Cooling set temp.	26°C	26°C	26°C	26°C
	Setback temp	28°C	28°C	28°C	x
	Efficiency class	x	x	x	B
	CoP	4.85	4.85	1.30[3]	4.85
	Pr. En. Conv.	3.167	3.56	2.60	2.36
	Energy need	230 kWh	213 kWh	210 kWh	217 kWh
	Primary energy need	48 kWh	44 kWh	161 kWh	45 kWh
	DHW supply	No DHW use	x	No DHW use	No DHW use
	Ventilation				
	Natural Vent.	-	x	-	-
	Mechanical Vent.	1 ac/h (outside airflow rate)	x	1 ac/h	1 ac/h
	Infiltration	-	-	0.04 ac/h[4]	-
	Ventilation Requirement		2.5 L/(s.person) (D)		
	Ventilation Requirement		0.3 L/(s.m^2) (D)		
	Airflow control		ASHRAE 62.1 – 2007		
	Interior lighting	No lighting	No lighting	No lighting	No lighting
	Exterior lighting	-	x	x	-
Analysis and results	Schedules				
	Occupancy	-	-	-	-
	Electrical equipment	08:00–18:00 (weekdays)	08:00–18:00 (weekdays)	08:00–18:00 (weekdays)	08:00–18:00 (weekdays)
	Lighting	-	-	-	-
	HVAC	08:00–18:00 (weekdays)	08:00–18:00 (weekdays)	08:00–18:00 (weekdays)	08:00–18:00 (weekdays)
	Evaluations				
	Annual energy need				
	For heating	454 kWh	715 kWh	822 kWh	567 kWh
	For cooling	230 kWh	213 kWh	406 kWh	217 kWh
	Outputs Exports	✓	✓	✓	✓

[1] *The closest window type to that of the test case*

[2] *Thermal bridges cannot be cancelled in the program*

[3] *CoP cannot be changed*

[4] *Minimum allowable value of the program*

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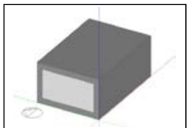
6.3 Analysis Results

The reference case is assessed by the four tools, and the monthly and annual evaluation results of the programs are obtained. The results provided in the standard are compared with those derived from the four tools. The comparison of the results for annual energy requirements for heating and cooling is presented in Table 11. Because of the reasons stated above, it is expected to observe differences in the evaluation results of the programs.

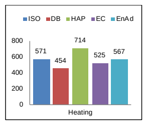
TABLE 11
COMPARISON OF THE RESULTS FOR THE REFERENCE CASE

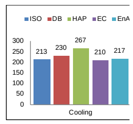


Test Case : **Worked example of TS EN ISO 13790**
# of zones : 1
Wall : W01 (U: 0,49)
Ground : internal floor
Roof : internal ceiling
Window : Wi01 (DG; U: 2,38; gl: 0,20)
WWR : 70%

Annual energy need

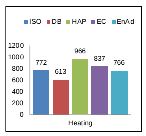
	ISO	DB	HAP	EC	EnAd
Heating	571	454	714	525	567
Cooling	213	230	267	210	217

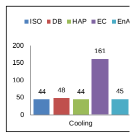




Annual primary energy need

	ISO	DB	HAP	EC	EnAd
Heating	772	613	966	837	766
Cooling	44	48	44	161	45





As seen in the annual energy requirements presented in Table 11, the results of the ISO standard are very close to those of EnAd and EnerCalc, the highest results are observed in HAP while the lowest ones can be seen in DesignBuilder. The discrepancies in the results for the annual energy requirements for cooling are generally very low, ranging from 2% in EnAd and EnerCalc to 8% in DesignBuilder, except from HAP (25%), while the results for heating differ by 1% in EnAd, 8% in EnerCalc, 21% in DesignBuilder, and 25% in HAP.

When common standards are used for the evaluation, very close results are derived. However, when the standards are changed, very diverse results can be observed. One reason for the discrepancies observed in the results is the differences in input data, and also the use of different climatic data caused the tools to calculate different solar gains, as well as different requirements for heating and cooling. Other different input data can be noted in the dimensions of the office considered, and since this test case is very small in size, any difference in dimensions causes discrepancies in the results. Differences that are specific to EnerCalc can be attributed to the uneditable construction type and window properties, non-cancellable thermal bridges and infiltration, and uncertainty in the schedule of internal gains.

Another reason for the discrepancies in the results can be attributed to the calculation method employed in the programs. Since the calculation methods are the same and the input data is very similar, EnAd comes up with almost the same results as the ISO standard; and EnerCalc is also very close to the ISO standard for heating (8% lower) and cooling (2% higher). Although it uses the same calculation method and climatic data, the differences of EnerCalc can be explained by the program limits described above. TS EN ISO 13790 states that there is a near 10% difference between the simple hourly method and the monthly calculation method. The standard also adds that a 5% uncertainty in input data may lead to a 30% difference in the results. Even when using the same standard, hourly and monthly calculation methods or minor differences in input data can lead to large discrepancies in the results. Coming to the other two programs, although DesignBuilder and HAP perform hourly simulations using similar weather data files and similar calculation methods, their results are very different, both from each other and from the results of the ISO standard. They give the highest values for cooling, whereas for heating DesignBuilder comes up with the lowest value and HAP produces the highest result. These two tools make evaluations according to the worst case scenario, considering heating and cooling design days, which are created based on the degree-day hours for heating and cooling determined from the climatic data. As shown in Table 10, IWEC data gives higher outside temperature values for Paris than ISO, whereas the solar radiation data is estimated to be lower than that of the ISO. In this case, the results of the simulation tools would be expected to be lower in terms of heating loads and higher cooling loads. Design Builder produces such results (21% lower heating; 8% higher cooling), while HAP gives the most divergent requirement values, with 25% higher heating needs and 25% higher cooling when compared to the results of the ISO standard.

Table 11 also shows the results from the annual primary energy requirement calculated by the programs. The discrepancies in the results are due to the differences in the efficiency of the equipment and the primary energy conversions used by the programs. Among all, the most different results are observed in EnerCalc due to the uneditable equipment efficiency values for the heater (0.63) and air conditioner (1.35) when compared to the others, which are 0.74 and 4.85.

7 CONCLUSIONS

This paper has emphasized the importance of the use of BEP evaluation tools during the design process. It also points out the differences between the program data structures of BEP evaluation tools and possible differences observed in the results due to the differences in their data structures. In this context, this study underlines that it is very important for the countries to develop their own tools by using their own legislations [28]. For a program to be applicable to any project, the user should know the program data structure of a soft tool as well as the validity, reliability and precision of its results. The data structure of a soft tool plays an important role both in the evaluations and the results. The data structure covers the database and program defaults as well as the data input required for the evaluation. Database includes the legislations, standards, climatic data, material library, equipment types and properties, whereas program defaults cover the calculation method, schedules, conversion coefficients and correlation coefficients. Data input, on the other hand, takes account of the definition methods of building form and HVAC system properties as well as the units of measurement and the type and quantity of input data. Any difference in such structures used by individual tools gives rise to differences in the evaluation results. In this respect, the designers/users should reconsider the suitability and applicability of the tools to a given context.

Acknowledgment

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