• IJKEM, INT. J. KNOWL. ENG. MANAGE., v.6, n.15 • FLORIANÓPOLIS, SC • JUL/OUT. 2017 • ISSN 2316-6517 •
Submissão: 28 mar. 2017. **Aceitação**: 11 mai. 2017. **Sistema de avaliação**: às cegas dupla (*double blind review*).
UNIVERSIDADE FEDERAL DE SANTA CATARINA (UFSC)
Patricia de Sá Freire e João Artur de Souza (Ed.), p. 120-141.

KNOWLEDGE ENGINEERING AND MANAGEMENT CONTRIBUTIONS IN THERMAL MULTI-ZONE BUILDING STUDIES

SIGMUNDO PREISSLER JR
Sapienza University of Rome and Federal University of Santa Catarina
M. Eng.
ORCID 000-0002-1178-3499
preissler@di.uniroma1.it

ALEXANDRE LEOPOLDO GONÇALVES
Programa de Pós-Graduação em Tecnologias da Informação e Comunicação – Universidade Federal de Santa Catarina
Doutor em Engenharia de Produção
ORCID 0000-0002-6583-2807
a.l.goncalves@ufsc.br

SUMMARY

Goal: To identify the profile of the Knowledge Engineering and Management publications into the Thermal Analysis in the Multi-zone Building Context.

Design / Methodology / Approach: Bibliometric Review

Results: This research has analyzed 135 papers and finally selected 35 resulting as strongly related to the proposed theme

Originality / value: From our preliminary researches, studies that address the scope of this work were not found.

Keywords: knowledge engineering and management, multi-zone building, thermal studies, bibliometric review.

CONTRIBUIÇÕES DA ENGENHARIA E GESTÃO DO CONHECIMENTO EM ESTUDOS TÉRMICOS DE EDIFÍCIOS MULTI-ZONA

RESUMO

Objetivo: identificar o perfil das publicações de Engenharia e Gestão do Conhecimento na Análise Térmica no Contexto do Edifício Multi-Zona.

Design/Metodologia/Abordagem: revisão bibliométrica.

Resultados: Esta pesquisa analisou 135 trabalhos e, finalmente, selecionou 35 resultando fortemente relacionado ao tema proposto.

Originalidade/valor: de nossas pesquisas preliminares, estudos que abordam o escopo deste trabalho não foram encontrados.

Palavras-chave: engenharia e gestão do conhecimento. edifícios multi-zona. estudos térmicos. revisão bibliométrica.

1 INTRODUCTION

The term Smart Energy (SE) (PREISSLER, 2015) has been used to refer to researches and development initiatives in the energy studies related to Smart Grids, Smart Cities and Smart Homes or Buildings. The term "smart" is commonly used to describe the use of technological innovation and Information Technologies (ITs) for automation purposes and resource savings (LUND et al., 2012).

Due to the high levels of CO2 emissions and the growth in power consumption it is becoming increasingly important, in the last years, to conduce scientific studies in order to understand and reduce the environmental impacts and also to generate contributions to household financial savings.

Knowledge Engineering and Management (KEM) is an interdisciplinary field which over the past 25 years has been using IT as a tool to "operationalize" the Knowledge Management (KM) problems (NONAKA, 2008) (RUS; LINDVALL, 2002). Assuming that the term "smart" is related to the use of IT, and considering that IT is also an important area of KEM studies, this paper deals with IT as the main point of convergence between SE and KEM.

That interdisciplinary area aims to capitalize on organizations' intellectual capital (ALAVI; LEIDNER, 2001). One important definition for KM, given by Davenport (1994) is that: "[…] knowledge management is the process of capturing, distributing, and effectively using knowledge". On other hand, KEM is inseparably connected with solutions in the IT area, "[…] it involves integrating knowledge into computer systems in order to solve complex problems" (FEIGENBAUM; MCCORDUCK, 1983) (JOOSS et al., 2015).

Thus, this research guide question is: "How does Knowledge Engineering and Management is present within Scientific Researches in Thermal Multi-zone Building Studies?". To answer this question it was necessary to conduct an investigation on the relationship between the aforementioned terms. Such research focused on analyzing the results from searches in scientific databases over the past 10 years.

The main goal of this paper is to present the scientific studies state-of-the-art related to the multi-zone heating control buildings. Special attention was drawn on studies using electrical-thermal analogy in a Smart Building context. This study is characterized as a bibliometric review format. First of all, we chosen the keywords related to the studied topics. Then, three scientific databases were elected to be used. Following, we performed the direct search and the abstracts were read in order to filter the content. Finally, we proceeded the complete reading from selected papers in the previous step. Partial and final results are analyzed and described throughout this document. At the end the final results as well as future forward in relation to the themes are discussed.

This paper is structured as follows: Section 2 presents the methodology used and Section 3 reports the research process. A final evaluation about the finalist papers is presented in Section 4. Section 5 presents the final remarks, conclusions and future works.

2 METHODOLOGY

The present paper presents a bibliometric review. We developed the review, initially searching terms in three important scientific databases over the past 10 years: IEEE®[1] Xplore (IEEEx), Scopus[2]® and Web of Science[3]® (WoS). For the analysis steps, tools as Microsoft Excel[4]® and Endnote[5]® software were used.

This study is characterized as descriptive, analytical and *bibliometric*. It can be characterized as a descriptive study because it seeks to describe all information which was collected during the research in all its stages. It is also analytic because at the end of each presented stage or along the steps the collected information is analyzed in order to check the hypotheses.

Bibliometry is a quantitative study from production aspects of a certain database, dissemination and use of recorded information (MACIAS-CHAPULA, 1998). The purpose is to show one condensed representation of information for storage and future inquiries (BARDIN, 1977). Despite the fact that these studies do not have a content analysis character, they are important in the generation of quantitative surveys documented with respect to a quantity of articles, authors, year of publication, among other indicators. These indicators could be used for the scientific community in future researches.

3 RESEARCH PROCESS

This review is given in x stages S and y steps let $x = \{a, b, c, d, e\}$ and $y = \{1,..., N\}$ for N been the maximum number of steps at the stage x. Where x is the set of papers selected in each x stage at step y. These stages and their results can be seen in Fig. *5* as well as details presented by Sections *3.1, 3.2, 3.3, 3.4* and *3.5.*

The relationship between Thermal Multi-zone Buildings and KEM studies were performed on the stage S_e, which is the complete reading of the papers.

[1] www.ieee.org
[2] www.scopus.com
[3] https://webofknowledge.com/
[4] www.microsoft.com
[5] www.endnote.com

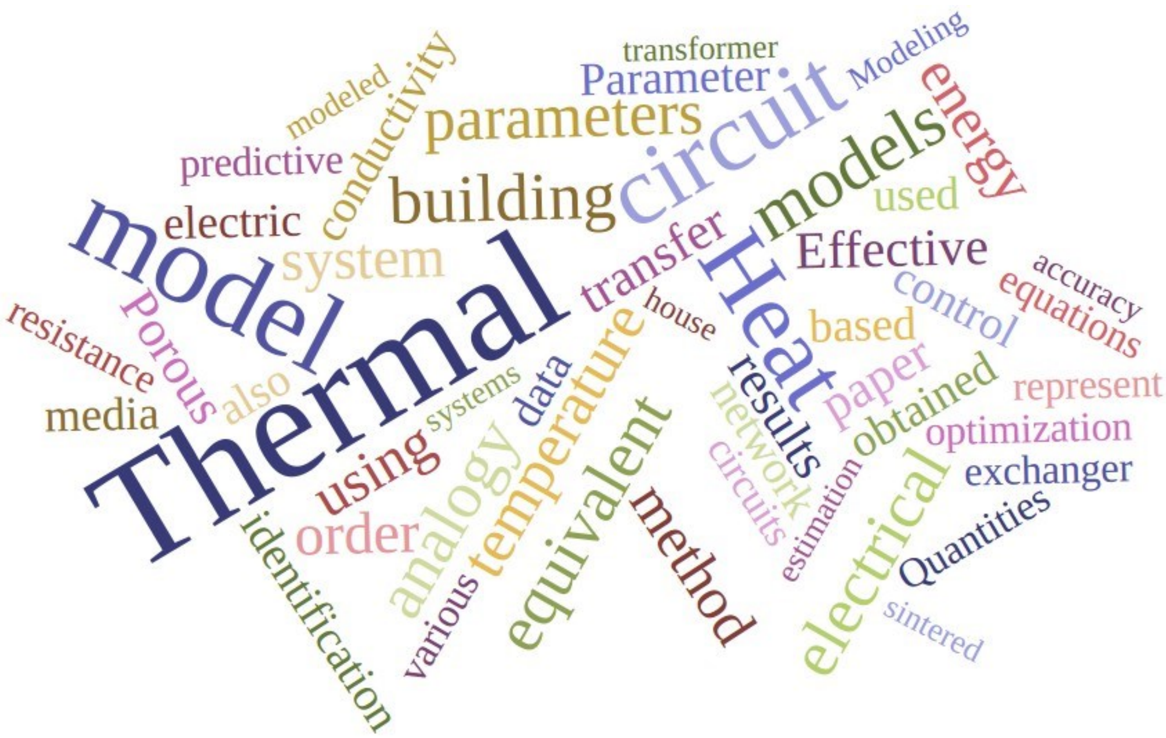
3.1 STAGE (A) – S_a

The purpose of this step was to figure out and select the keywords that would be used to search into the databases. The keywords used in this research process were obtained from seven random papers (RAMIREZ-LABOREO; SAGUES; LLORENTE, 2014) (SWIFT; MOLINSKI; LEHN, 2001) (CHEN; FU; XU, 2015) (FLOREZ; MANTELLI; NUERNBERG, 2013) (LEEUWEN et al., 2015) (PARNIS, 2012) (PARK et al., 2013) which were aligned with the subject to be searched.

Figure 1 shows the 50th most frequently used words among titles, keywords and abstracts from those seven aleatory papers. The ten most frequently used words are, in order of appearance, *thermal, model, circuit, heat, models, analogy, electrical, building, parameters* and *temperature*.

In order to have a global understanding of the sample space these ten words were applied to the three databases or using the "OR" operator ($\vee$). Searches in Meta data were used which means that matches among the chosen words (S_a) were being looked for within titles, keywords and abstracts from the databases.

Figure 1: Cloud words S_a



Source: Authors (2017)

Equation *1* presents that the global set S_a of papers $p \in P$ must have in their meta data the terms $\{t_1, ..., t_{10}\}$ which correspond to the ten most frequently used words found.

$$S_a = \{ p \in P \mid P \supset \{t_1 \lor t_3 \lor t_4 \lor t_5 \lor t_6 \lor t_7 \lor t_8 \lor t_9 \lor t_{10}\}\} \quad (1)$$

The S_a search found 26,745,000 papers of which 13,372,500 are from Scopus, 10,430,550 from WoS and 4,011,750 from IEEEx. This huge number is due to the use of the "OR" operator ($\lor$). Once stage S_a have found 26,745,000, all the "OR" $\lor$ operators were changed to "AND" operators $\land$. In that case the search returned zero papers. In order to keep searching for papers aligned with the scope of this paper, we changed the strategy and other word combinations were applied.

3.2 STAGE (B) – S_b

In this section some strategies used in order to obtain better fitting between the found papers and the selected terms from S_a are presented. These strategies or combinations c are explained as follow.

At this stage S_b the search terms (from S_a) were applied in the three scientific bases in different c combinations. So S_b^c is the combination c for the stage S_b. Equation *2* presents that the first search of the first set S_b^1 of papers $p \in P$ must have in their meta data the terms $\{t1, ..., t6\}$.

$$S_b^1 = \{ p \in P \mid P \supset \{t_1 \land t_2 \land t_3 \land t_4 \land t_5 \land t_6\}\} \quad (2)$$

Where t_1 to t_6 are respectively *thermal, model**[6], *circuit*, heat*, build** and *zone**. In S_b^1 a total of 16 papers were found: 12 from Scopus, 3 from WoS and 1 from IEEEx.

The second search S_b^2 from S_a excluded the term t_2 (Eq. *3)*. In that case the total of papers changed to 31 papers (20 from Scopus, 8 from WoS and 3 from IEEEx).

$$S_b^2 = \{ p \in P \mid P \supset \{t_1 \land t_3 \land t_4 \land t_5 \land t_6\}\} \quad (3)$$

If the terms t_2 and t_3 are excluded (Eq. *4)* the total amount of papers grows up to a total of 2446 where 1465 come from Scopus, 893 from WoS and 88 from IEEEx.

$$S_b^3 = \{ p \in P \mid P \supset \{t_1 \land t_4 \land t_5 \land t_6\}\} \quad (4)$$

The fourth search for the S_a, showed by *Eq.6* uses the equivalent of Eq. *4*. However, the term t_6 we changed by "multi-zone".

[6] The asterisk symbol ('*') is used as a wildcard, which tells the search engine to replace in that position any other character.

$$S_b^4 = \{ p \in P \mid P \supset \{t_1 \wedge t_4 \wedge t_5 \wedge t_6\}\} \quad (5)$$

The search S_b^4 has returned a total of 162 papers where 87 were from Scopus, 60 from WoS and 15 from IEEEx.

$$S_b^5 = \{ p \in P \mid P \supset \{t_1 \wedge t_4 \wedge t_5 \wedge t_6\} \wedge l = Eng \wedge y \geq 2006\} \quad (6)$$

Search S_b^5 found a total of 135 papers. 67 of them were from Scopus, 53 from WoS and 15 from IEEEx as can be seen on Tab. 1.

Table 1: Summary of results found in S_b^5

Database	Frequency	Percentage
IEEEx	15	11%
Scopus	67	50%
WoS	53	39%
TOTALS	**135**	**100%**

Source: Authors (2017)

Let be S_b^5, the last search for S_b then $S_b \leftarrow S_b^5$.

3.3 STAGE (C) – S_c

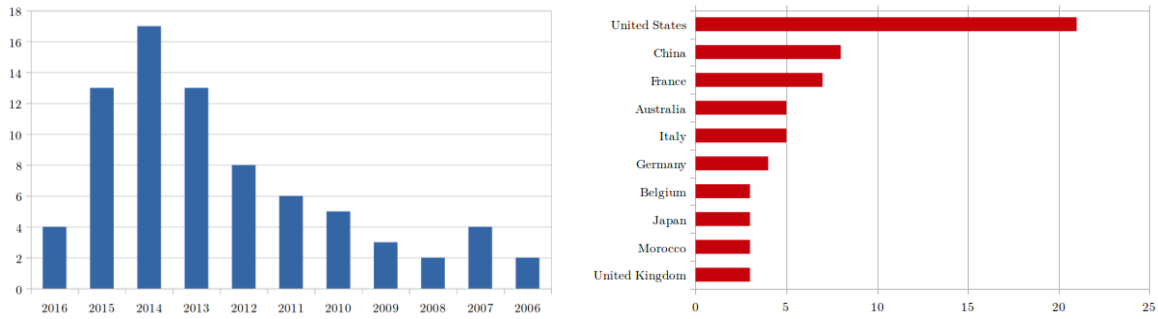
In this stage S_c^1, the 135 documents were exported to EndNote application. The goal was to find out duplicated papers that can be found in S_b^5 and that are indexed to more than one of those investigated database. We found 57 duplicate papers for S_c^1, resulting in a total of 78 papers.

In stage S_c^2 we performed the download of files (S_c^1) from databases or other sources available on the Internet. In this stage S_c^2 it was not possible to download one file once it was available on the paid database. Considering that these researches don't have free access, the search resulted in 77 papers. So $S_c \leftarrow S_c^2$.

The 77 papers were analyzed in relation to the year (Fig. 2(a)) and country of publication (Fig. 2(b)).

Figure 2: Distribution of publications S_c^2

(a) by year – Sc (b) by Country - Sc



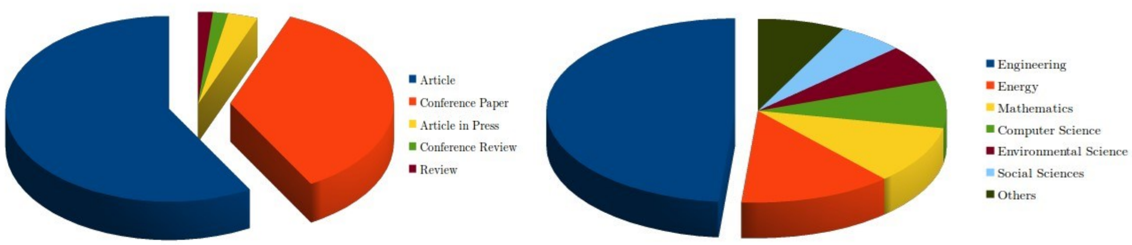
Source: Authors (2017)

The year 2014 leads the years' list with the highest number of publications followed by the years 2013 and 2015. The USA was the country with the higher number of papers on stage S_c being followed by China and France. In this graph (Fig. 2(b)) only the top 10 countries were listed.

The two most frequently found types of papers were Articles and Conference Papers (Fig. 3(a)). These 77 items are mainly concentrated in the areas of Engineering, Energy, Mathematics and Computer Science. Social Sciences and Environmental Sciences are on the bottom of the list and other areas do not have an extensive number of publications (Fig. 3(b)).

Figure 3: Proportion of publications S_c^2

(a) by Type - S_c (b) by Subject Area - S_c

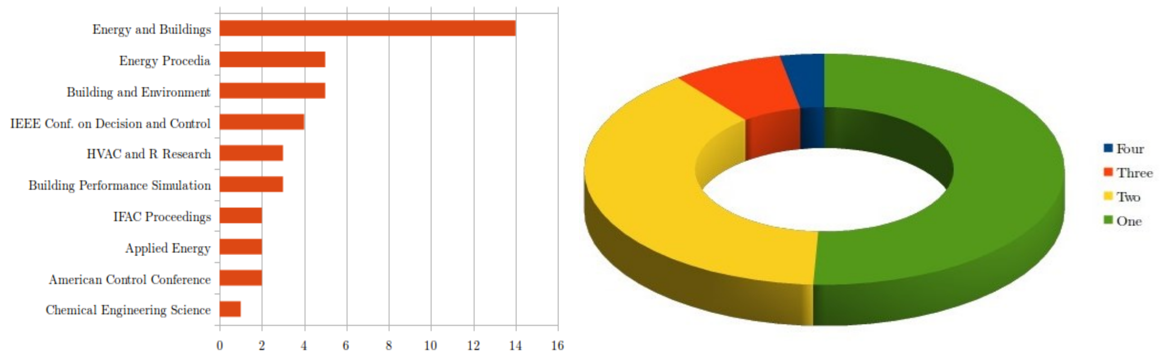


Source: Authors (2017)

The sources presented by Fig. 4(a) which lead the list of publications are *Energy and Building Journal*, *Energy Procedia* and *Building and Environment*. In the top 10 list both Journals and Conferences titles can be found.

Figure 4: Amount of publications S_c^2

(a) by Source - S_c (b) by Authors - S_c



Source: Authors (2017)

Figure 4(b) shows the number of papers by the author. 50.75% of them appear in only one publication, 38.81% in two, 7.46% in three and 2.99% in four publications. These picture shows that a large concentration of these studies is held by a relatively small group of researchers.

3.4 STAGE (D) – S_d

In step S_d we realize the reading of all abstracts of papers previously located in stage S_c. The reading of abstracts aimed to select only those papers that met the scope of this review.

The abstracts were read in order to identify the correspondence with this paper purpose and the publications found. The criterion we used in the readings was to identify whether the abstracts had scientific research evidence related to the issues, more specifically to the KEM area and thermal studies. The words and phrases that might identify the involved works with KEM search area were chosen based on literature related to the area (BOVO, 2011) (PPGEGC, 2014). The stage S_d resulted in a total of 36 papers.

3.5 STAGE (E) – S_e

In the prior papers filtering stage S_e, we performed the total reading of the papers found in the previous stage S_d. Similarly to the reading of abstracts, the total reading sought to identify the alignment of those works found in S_d with the scope of this review.

At this stage, it was also sought to identify the relationship between Thermal Multi-zone Building and KEM studies. The stage S_e resulted in a total of 35 finalist papers.

4 FINAL RESULTS EVALUATION

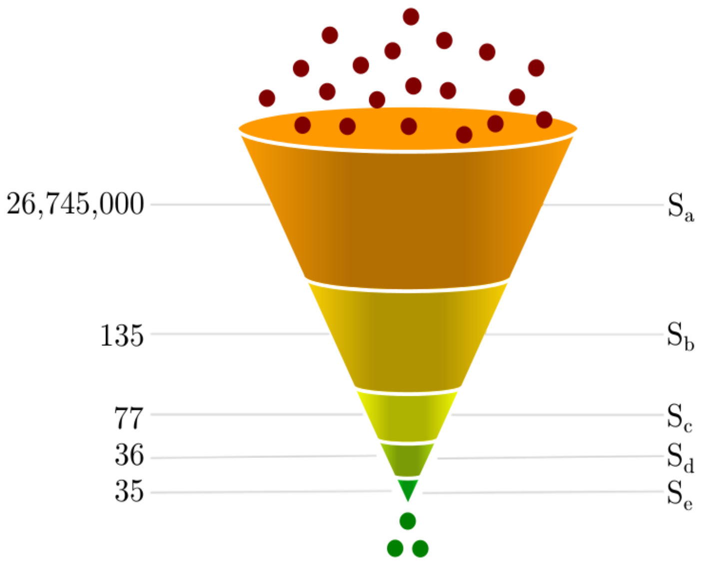
This section is responsible for presenting evaluations of the stages S_a to S_e of this bibliometric review and a more detailed assessment of the papers found in stage S_e, here named *finalist papers*.

The results from the searches S_a to S_e can be found in Fig. *5*. S_a starts with a universe of 26,745,000 papers and S_e finalizes presenting 35 papers. The funnel presents the quantitative results (funnel on the left side) obtained in this research as well as the stage identification of each step (funnel on the right side). S_x represents the set of publications S obtained in each step x.

The large amount of duplicate papers detected in S_c^1 stage may indicate a high quality of scientific work due to the fact that they are indexed in more than one database

In stage S_e the complete reading of the 35 finalist papers seeking to identify their characteristics and their relationship with KEM. Tables *2a* and *2b* show the grouped results of characteristics of each paper. Table *3* shows a summary of the software that was used by the authors to perform tests and evaluations in their studies.

Figure 5: Bibliometric review funnel



Source: Authors (2017)

Regarding to the scope of work studied, 100% of those papers are explicitly classified in a *multi-zone* building study context. Although the word *"heat*"* has been used in searching of these databases, 57.1% of those 35 finalist papers explicitly worked on *heating* devices. 40% of them have an explicit relationship with *cooling* studies.

Only 2.9% of the articles deal with the CO_2 *emission* calculation and offer some kind of control plane to *act on the heaters/coolers* devices. Only 3% of the finalist papers declare explicitly use of the *outdoor temperature as an input* to calculate the internal temperature, that is, they consider the external temperature as a directly proportional factor changing the internal temperature.

Table 2a: Scope, Features, Constraints, IT Approaches and Methodologies used by the final sample

		Scope		Features						Constraints				IT Approaches					Methodologies				
Id	**References**	**Cooling**	**Heating**	**Actuating on Devices**	**Makes Predictions**	**Prior Knowledge**	**Occupancy Profiles**	**Uses Tout as Input**	**Weather Forecast**	**CO2 Emissions**	**Comfort**	**Economic**	**Peak Load**	**Genetic Algorithm**	**Fuzzy**	**Multi-agents**	**Machine Learning**	**Neural Networks**	**Electrical-Thermal**	**Graph Representation**	**Parameter Identification**	**System Identification**	**Model Predictive Controller**
01	Ascione et al. (2016)		x		x	x	x		x		x			x									x
02	Bekkouche et al. (2013)	x									x								x		x		
03	Bengea et al. (2014)	x	x		x		x		x		x		x										x
04	Benhamou e Bennouna (2013)	x									x												
05	Buonomano et al. (2016)	x									x								x		x		
06	Chel, Janssens e De Paepe (2015)		x																				
07	Ferdyn-Grygierek (2014)	x	x								x												
08	Frances, Escriva e Ojer (2014)		x						x												x		
09	Genc e Sehgal (2014)	x			x		x		x		x	x	x							x	x	x	x
10	Goethals, Breesch e Janssens (2011)	x			x						x										x		
11	Goyal, Liao e Barooah (2011)		x		x	x					x								x	x	x		
12	Gupta et al. (2014)	x	x		x		x				x	x							x		x		
13	Hamdy, Hasan e Siren (2010)		x			x				x		x		x									
14	Hao et al. (2015)		x		x						x					x			x	x			x
15	Hu e Karava (2013)	x			x		x	x	x		x								x		x	x	x
16	Hu e Karava (2014)	x			x			x	x		x							x	x			x	
17	Huang et al. (2013)		x		x						x				x			x			x		
18	Huang, Chen e Hu (2015)		x		x						x							x			x		x
19	Jassar, Liao e Zhao (2009)	x			x						x										x		x
21	Liao e Dexter (2010)		x		x			x			x										x		x
22	Ma et al. (2012)	x			x		x					x	x									x	x
23	Morosan et al. (2011a)		x			x	x				x												x
24	Morosan et al. (2011b)		x				x				x												x

Source: Authors (2017)

Table 2b: Scope, Features, Constraints, IT Approaches and Methodologies used by the final sample

		Scope		Features						Constraints				IT Approaches					Methodologies				
Id	**References**	**Cooling**	**Heating**	**Actuating on Devices**	**Makes Predictions**	**Prior Knowledge**	**Occupancy Profiles**	**Uses Tout as Input**	**Weather Forecast**	**CO2 Emissions**	**Comfort**	**Economic**	**Peak Load**	**Genetic Algorithm**	**Fuzzy**	**Multi-agents**	**Machine Learning**	**Neural Networks**	**Electrical-Thermal**	**Graph Representation**	**Parameter Identification**	**System Identification**	**Model Predictive Controller**
25	Mukherjee, Mishra e Wen (2012)		x		x	x					x								x	x			x
26	Nassif e Moujaes (2008)					x					x										x		
27	Okuyama e Onishi (2012)		x			x					x										x		
28	Radecki e Hencey (2013)		x		x														x	x	x	x	x
29	Sobhy, Brakez e Benhamou (2014)	x	x			x					x										x		
30	Tsitsimpelis e Taylor (2015)			x		x															x		
31	Wen et al. (2013)				x						x	x							x	x	x		
32	Xu et al. (2013)	x	x				x		x		x	x	x										
33	Zeng, Zhang e Kusiak (2015)				x	x					x							x					
34	Zhang et al. (2013)										x										x		
35	Zhuang, Li e Chen (2007)		x						x		x										x		

Source: Authors (2017)

Table 3: Software used to perform Simulations, Tests and Evaluations

Refs.	BCVTB	DETECt	EnergyPlus	ESP-r	Fluent CFD	IDA-ICE	Matlab	PowerDevs	TRNSYS	YALMIP
Ascione et al. (2016)			x				x			
Bekkouche et al. (2013)										
Bengea et al. (2014)										
Benhamou e Bennouna (2013)									x	
Buonomano et al. (2016)		x								
Chel, Janssens e De Paepe (2015)									x	
Ferdyn-Grygierek (2014)				x						
Frances, Escriva e Ojer (2014)			x	x				x		
Genc e Sehgal (2014)			x				x		x	
Goethals, Breesch e Janssens (2011)									x	
Goyal, Liao e Barooah (2011)							x			
Gupta et al. (2014)										
Hamdy, Hasan e Siren (2010)						x	x			
Hao et al. (2015)							x			x
Hu e Karava (2013)										
Hu e Karava (2014)										
Huang et al. (2013)										
Huang, Chen e Hu (2015)										
Jassar, Liao e Zhao (2009)										
Liao e Dexter (2010)										
Ma et al. (2012)	x		x				x			
Morosan et al. (2011a)							x			
Morosan et al. (2011b)							x			
Mukherjee, Mishra e Wen (2012)										
Nassif e Moujaes (2008)										
Okuyama e Onishi (2012)										
Radecki e Hencey (2013)			x				x			
Sobhy, Brakez e Benhamou (2014)									x	
Tsitsimpelis e Taylor (2015)							x			
Wen et al. (2013)					x					
Xu et al. (2013)			x				x			
Zeng, Zhang e Kusiak (2015)										
Zhang et al. (2013)					x					
Zhuang, Li e Chen (2007)							x			

Source: Authors (2017)

Approximately 23% of those papers use *weather forecast* for the calculation of future temperatures and almost 26% of the articles have some kind of user consumption *profile* calculation or they use the household profile as input for their calculations. In these cases KEM methods with regard to the *elicitation* of knowledge, mainly in *use* and *extraction of the knowledge* from the households were detected.

Finally, 28.6% of the papers explicitly require some *prior knowledge* about the characteristics or parameters from the envelope (previous data knowledge) for purposes of calculating the future internal temperature. Despite the fact that any explicit link with KEM was found, methods of extraction and reuse of knowledge were detected.

Moreover, 51.4% of those 35 papers do some kind of forecasting or provide methods for calculating or *predicting* future temperature values, power consumption, among others. Some KEM methods as *creation* and *transformation of knowledge* were identified in this set of papers.

In respect to constraints used by the authors in the calculations, 11.4% use *peak load* as a constraint in the optimization calculations, 17.1% use *economic constraints* related to the price of kWh and 80% of them make use of restrictions related to *thermal comfort*. This thermal comfort is commonly associated with the approach of calculating the internal temperature as near as possible to the desired inside temperature. Some articles also make use of more than one constraint optimization in their calculations simultaneously.

As it relates to Information Technology (IT) approaches, 2.9% use *Fuzzy* algorithms or *multi-agents* while 5.7% use *genetic algorithms* as a resolution method. The most widely used IT method however, is the artificial *neural networks* (11.4%). 77% of those works do not have explicit use of a IT algorithm, thus those papers have only their own models for the heating/cooling problems presented and seek to support them through simulations and mathematician evaluations.

The most commonly used methods for the development of finalist papers are *Model Predictive Controller* with 37.1%, which is directly related to the characteristic of 51.4% of papers to do some kind of future calculations. Following the *Electrical-Thermal analogy* (28.6%) that is well spread by papers that compare the dynamics of heating/cooling a building with an electrical circuit. The *Parameter Identification* technique is used by over half of the papers (57.1%), followed by the methods of *System Identification* and *Graph Representation* with 17.1% and 14.3% respectively. Some of those papers use more than one method. During the readings the use of software for simulations, assessments and calculations of the proposed models (Table *4) were also detected.* Most of the papers (34.3%) use the Matlab[7] *computer system*.

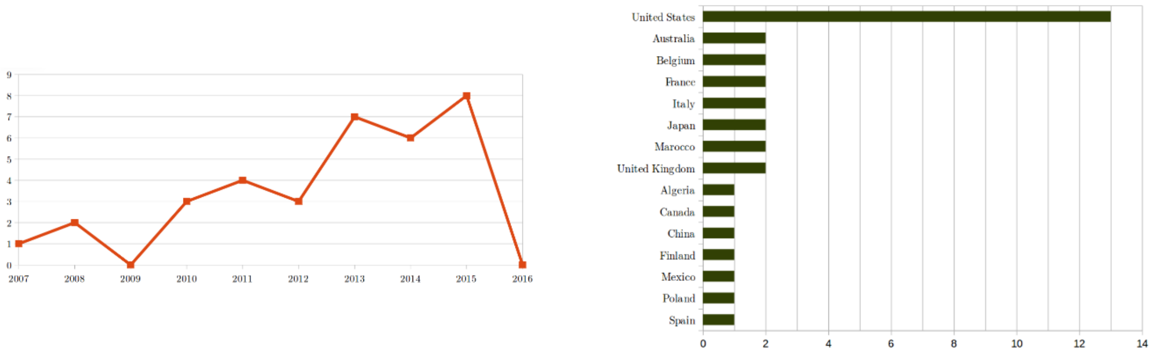
Following, it was possible to identify the EnergyPlus[7] and TRNSYS[8] systems with 17.1% and 14.3% respectively. ESP-r[9] or Fluent CFD[10] were used by 5.7% of the papers and Building

[7] https://energyplus.net/

Controls Virtual Test Bed[11] (BCVTB), DETECt[12], IDA-ICE[13], PowerDevs[14] or Yalmip[15] systems were found in 2.9% of papers. Some papers made use of more than one computer system.

Figure 6: Distribution of papers S_e^2

(a) by Year - S_e (b) by Country - S_e

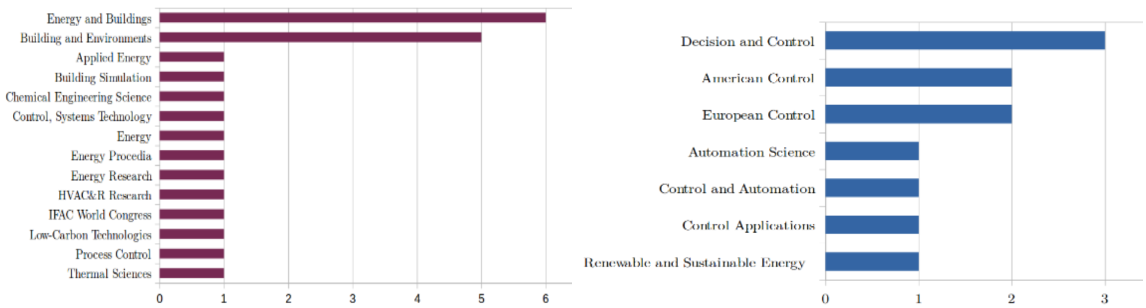


Source: Authors (2017)

Fig. 6(a) shows the amount of found scientific works grouped by year of publication. The year 2016 presents a significant drop in the number of publications. This is due, in large part, to the fact that this paper was finalized in the beginning of the current year 2016, which justifies these low numbers.

Figure 7: Quantity of papers S_e^2

(a) by Journal - S_e (b) by Conference - S_e



Source: Authors (2017)

[8] http://www.trnsys.com/
[9] http://www.esru.strath.ac.uk/Programs/ESP-r.htm
[10] http://www.ansys.com/Products/Fluids/Heat-Transfer
[11] https://simulationresearch.lbl.gov/bcvtb
[12] http://www.latermotecnica.net/pdf riv/201309/20130915001 1.pdf
[13] http://www.equa.se/en/ida-ice
[14] https://sourceforge.net/projects/powerdevs/
[15] http://users.isy.liu.se/johanl/yalmip/pmwiki.php?n=Main.WhatIsYALMIP

Fig. 6(b) shows the list with the countries from where the authors of publications are. United States tops the list with a significant difference to the second and later. The analysis of the 35 finalist papers was split in Journals and Conference Papers. Fig. 7(a) shows the list of Journals while Fig. 7(b) shows the Conference Papers.

5 CONCLUSION

This paper aimed to present a bibliometric review about KEM contributions in Thermal Multi-zone Buildings studies. We analyzed 135 (S_b) papers and finally selected 35 (S_e) resulting as strongly related to the proposed theme.

The choices of keywords were done through the analysis of seven random papers, which were previously known by these authors. Those words were analyzed, selected and applied to the three scientific databases (IEEEx, Scopus and WoS). Several combinations of these words have been made and executed into the databases in order to identify the alignment between the results and research subject matter by the original seven articles. After choosing the number of items to be analyzed (S_b), we made some analysis and filters which turn in 35 finalist papers. These finalist articles were analyzed and grouped by tables and graphs. They were also descriptively analyzed.

The main contribution of this paper is related to the presentation of the profile from the scientific researches involving the KEM and Thermal Multi-zone Buildings studies areas and their features, particularly in electrical-thermal analogy context.

The funnel (Fig. 5) presents the quantitative results (left side funnel) obtained in this research as well as the process used in each step (right side funnel). In this context, S_x represents the set of publications S obtained in each step x.

The KEM methods identified in stage S_e were: *extraction*, *reuse*, *creation* and *transformation of knowledge*. The elicitation method was also detected, mainly in the *use* and *extraction of knowledge* from the households. Such methods were not explicitly mentioned as KEM methods but they could be identified in the readings and in relation to the context.

Some difficulties or conditions were faced during this research. One of these problems was the difficulty to access scientific papers which are only available for sale, even to associated institutions. A large amount of double indexed papers caused important reduction between stages S_b and S_c. Even more, abstracts that did not have strong relationship with their titles causing “not aligned” papers in reading abstracts step were found.

For future works we suggest the use of different keywords related to the KEM area to improve the assertiveness of the results in the last stage S_e. Moreover, for further *bibliometric* researches, it would be advisable to use a local computer system with some sort of data mining in order to streamline the process between steps.

ACKNOWLEDGMENT

We would like to thank to BE Mundus Project from European Commission[16] and to the "Support Fund for Maintenance and Development of Santa Catarina State-Brazil for Higher Education (UNIEDU)".

REFERENCES

ALAVI, M.; LEIDNER, D. E. Review: Knowledge management and knowledge management systems: Conceptual foundations and research issues. *MIS quarterly*, JSTOR, p. 107–136, 2001.

ASCIONE, F. et al. Simulation-based model predictive control by the multi-objective optimization of building energy performance and thermal comfort. *Energy and Buildings*, Elsevier, v. 111, p. 131–144, 2016.

BARDIN, L. Content analysis. *Editions Lisbon*, 1977.

BEKKOUCHE, S. et al. Influence of the compactness index to increase the internal temperature of a building in Saharan climate. *Energy and Buildings*, Elsevier, v. 66, p. 678–687, 2013.

BENGEA, S. C. et al. Implementation of model predictive control for an HVAC system in a mid-size commercial building. *HVAC&R Research*, Taylor & Francis, v. 20, n. 1, p. 121–135, 2014.

BENHAMOU, B.; BENNOUNA, A. Energy Performances of a Passive Building in Marrakech: Parametric Study. *Energy procedia*, Elsevier, v. 42, p. 624–632, 2013.

BOVO, A. B. A Knowledge Discovery Model of Inherent in the Temporal Evolution of the Relationships among Textual Elements. Tese (Doutorado) — Ph.D. Federal University of Santa Catarina, Florianóópolis, Brazil, 2011.

BUONOMANO, A. et al. Dynamic building energy performance analysis: A new adaptive control strategy for stringent thermohygrometric indoor air requirements. *Applied Energy*, Elsevier, v. 163, p. 361–386, 2016.

CHEL, A.; JANSSENS, A.; De Paepe, M. Thermal performance of a nearly zero energy passive house integrated with the air–air heat exchanger and the earth–water heat exchanger. *Energy and Buildings*, Elsevier, v. 96, p. 53–63, 2015.

[16] This publication reflects the authors' views. Thus, the Commission cannot be held responsible for any use that may be made of the information contained therein.

CHEN, Q.; FU, R.-H.; XU, Y.-C. Electrical circuit analogy for heat transfer analysis and optimization in heat exchanger networks. *Applied Energy*, Elsevier, v. 139, p. 81–92, 2015.

DAVENPORT, T. H. Saving IT's Soul: Human-Centered Information Management. *Harvard business review*, ERIC, v. 72, n. 2, p. 119–31, 1994.

FEIGENBAUM, E. A.; MCCORDUCK, P. *The fifth generation*. [S.l.]: Addison-Wesley Pub., 1983.

FERDYN-GRYGIEREK, J. Indoor environment quality in the museum building and its effect on heating and cooling demand. *Energy and Buildings*, Elsevier, v. 85, p. 32–44, 2014.

FLOREZ, J. P. M.; MANTELLI, M. B.; NUERNBERG, G. G. Effective thermal conductivity of sintered porous media: Model and experimental validation. *International Journal of Heat and Mass Transfer*, Elsevier, v. 66, p. 868–878, 2013.

FRANCES, V. M. S.; ESCRIVA, E. J. S.; OJER, J. M. P. Discrete event heat transfer simulation of a room. *International Journal of Thermal Sciences*, Elsevier, v. 75, p. 105–115, 2014.

GENC, S.; SEHGAL, H. Distributed estimation of lumped parameters of multi-zone small-middle size commercial buildings with minimal observations & implementation. In: IEEE. *Control Applications (CCA), 2014 IEEE Conference on*. [S.l.], 2014. p. 2003–2008.

GOETHALS, K.; BREESCH, H.; JANSSENS, A. Sensitivity analysis of predicted night cooling performance to internal convective heat transfer modelling. *Energy and Buildings*, Elsevier, v. 43, n. 9, p. 2429–2441, 2011.

GOYAL, S.; LIAO, C.; BAROOAH, P. Identification of multi-zone building thermal interaction model from data. In: IEEE. *Decision and Control and European Control Conference (CDC-ECC), 2011 50th IEEE Conference on*. [S.l.], 2011. p. 181–186.

GUPTA, S. K. et al. Building Temperature Control With Active Occupant Feedback. In: 19th *World Congress, The International Federation of Automatic Control, Cape Town, South Africa*. [S.l.: s.n.], 2014.

HAMDY, M.; HASAN, A.; SIREN, K. Optimum design of a house and its HVAC systems using simulation-based optimisation. *International Journal of Low-Carbon Technologies, Oxford University Press*, p. ctq010, 2010.

HAO, H. et al. Distributed Flexibility Characterization and Resource Allocation for Multi-zone Commercial Buildings in the Smart Grid. *Energy*, 2015.

HU, J.; KARAVA, P. Modeling and Predictive Control of Mixed-Mode Buildings with MatLab/GenOpt. In: ASCE. AEI 2013@ *sBuilding Solutions for Architectural Engineering*. [S.l.], 2013. p. 276–285.

HU, J.; KARAVA, P. A state-space modeling approach and multi-level optimization algorithm for predictive control of multi-zone buildings with mixed-mode cooling. *Building and Environment*, Elsevier, v. 80, p. 259–273, 2014.

HUANG, H.; CHEN, L.; HU, E. A neural network-based multi-zone modeling approach for predictive control system design in commercial buildings. *Energy and Buildings*, Elsevier, v. 97, p. 86–97, 2015.

HUANG, H. et al. Multi-zone temperature prediction in a commercial building using artificial neural network model. In: IEEE. *Control and Automation (ICCA), 2013 10th IEEE International Conference on*. [S.l.], 2013. p. 1896–1901.

JASSAR, S.; LIAO, Z.; ZHAO, L. Adaptive neuro-fuzzy based inferential sensor model for estimating the average air temperature in space heating systems. *Building and environment*, Elsevier, v. 44, n. 8, p. 1609–1616, 2009.

JOOSS, C. et al. Integrative Knowledge Management in Interdisciplinary Research Clusters. *International Journal of Advanced Corporate Learning (iJAC)*, v. 8, n. 3, p. 17–22, 2015.

LEEUWEN, R. van et al. House thermal model parameter estimation method for Model Predictive Control applications. In: IEEE. *PowerTech, 2015 IEEE Eindhoven*. [S.l.], 2015. p. 1–6.

LIAO, Z.; DEXTER, A. L. An inferential model-based predictive control scheme for optimizing the operation of boilers in building space-heating systems. *Control Systems Technology, IEEE Transactions on*, IEEE, v. 18, n. 5, p. 1092–1102, 2010.

LUND, H. et al. From electricity smart grids to smart energy systems–a market operation based approach and understanding. *Energy*, Elsevier, v. 42, n. 1, p. 96–102, 2012.

MA, J. et al. Demand reduction in building energy systems based on economic model predictive control. *Chemical Engineering Science*, Elsevier, v. 67, n. 1, p. 92–100, 2012.

MACIAS-CHAPULA, C. A. The role of informetrics and scientometrics in the national and international perspective. *Ciência da Informação*, SciELO Brasil, v. 27, n. 2, p. nd–nd, 1998.

MOROSAN, P.-D. et al. A distributed MPC strategy based on Benders decomposition applied to multi-source multi-zone temperature regulation. *Journal of Process Control*, Elsevier, v. 21, n. 5, p. 729–737, 2011.

MOROSAN, P.-D. et al. Distributed MPC for multizone temperature regulation with coupled constraints. In: *IFAC World Congress*. [S.l.: s.n.], 2011. p. 729–737.

MUKHERJEE, S.; MISHRA, S.; WEN, J. T. Building Temperature Control: A Passivity-Based Approach. In: IEEE. *51st IEEE Conference on Decision and Control*. [S.l.], 2012. p. 6903–6907.

NASSIF, N.; MOUJAES, S. A cost-effective operating strategy to reduce energy consumption in a HVAC system. *International Journal of Energy Research*, Wiley Online Library, v. 32, n. 6, p. 543–558, 2008.

NONAKA, I. *The knowledge-creating company*. [S.l.]: Harvard Business Review Press, 2008.

OKUYAMA, H.; ONISHI, Y. System parameter identification theory and uncertainty analysis methods for multi-zone building heat transfer and infiltration. *Building and Environment*, Elsevier, v. 54, p. 39–52, 2012.

PARK, H. et al. Modeling of a Building System and its Parameter Identification. *Journal of Electrical Engineering & Technology*, v. 8, n. 5, p. 975–983, 2013.

PARNIS, G. *Building Thermal Modelling Using Electric Circuit Simulation*. Dissertação de Mestrado. Photovoltaic and Renewable Energy Engineering, University of New South Wales. Sydney, Australia, 2012.

PPGEGC. Interaction of Areas in the Program Query Object Search. *Department Directives*, Engineering and Knowledge Management Department. Federal University of Santa Catarina, Brazil, 2014.

PREISSLER, S. J. How does the Knowledge Engineering has contributed for Smart Energy Technologies? *Climate Innovation and Sustainable Development Systems*, III International Congress on Energy Efficiency, 2015.

RADECKI, P.; HENCEY, B. Online thermal estimation, control, and self-excitation of buildings. In: IEEE. *Decision and Control - CDC. 2013 IEEE 52nd Annual Conference on*. [S.l.], 2013. p. 4802–4807.

RAMIREZ-LABOREO, E.; SAGUES, C.; LLORENTE, S. Thermal modeling, analysis and control using an electrical analogy. In: IEEE. *Control and Automation (MED), 2014 22nd Mediterranean Conference of*. [S.l.], 2014. p. 505–510.

RUS, I.; LINDVALL, M. Knowledge management in software engineering. *IEEE software*, IEEE Computer Society, v. 19, n. 3, p. 26, 2002.

SOBHY, I.; BRAKEZ, A.; BENHAMOU, B. Effect of thermal insulation and ground coupling on thermal load of a modern house in Marrakech. In: IEEE. *Renewable and Sustainable Energy Conference (IRSEC), 2014 International*. [S.l.], 2014. p. 425–430.

SWIFT, G.; MOLINSKI, T. S.; LEHN, W. A fundamental approach to transformer thermal modeling. I. Theory and equivalent circuit. *Power Delivery, IEEE Transactions on*, IEEE, v. 16, n. 2, p. 171–175, 2001.

TSITSIMPELIS, I.; TAYLOR, C. J. Partitioning of indoor airspace for multi-zone thermal modelling using hierarchical cluster analysis. In: IEEE. *Control Conference (ECC), 2015 European*. [S.l.], 2015. p. 410–415.

WEN, J. T. et al. Building temperature control with adaptive feedforward. In: IEEE. *Decision and Control (CDC), 2013 IEEE 52nd Annual Conference on*. [S.l.], 2013. p. 4827–4832.

XU, Y. et al. Optimal building energy management using intelligent optimization. In: IEEE. *Automation Science and Engineering (CASE), 2013 IEEE International Conference on*. [S.l.], 2013. p. 95–99.

ZENG, Y.; ZHANG, Z.; KUSIAK, A. Predictive modeling and optimization of a multi-zone HVAC system with data mining and firefly algorithms. *Energy*, Elsevier, v. 86, p. 393–402, 2015.

ZHANG, W. et al. Building energy simulation considering spatial temperature distribution for nonuniform indoor environment. *Building and Environment*, Elsevier, v. 63, p. 89–96, 2013.

ZHUANG, Z.; LI, Y.; CHEN, B. A mathematical model for a house integrated with an elevated Chinese kang heating system. In: CITESEER. *Proceedings of the 10th International Building Performance Simulation Association Conference and Exhibition, China*. [S.l.], 2007.