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

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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® Xplore (IEEEX), Scopus® and Web of Science® (WoS). For the analysis steps, tools as Microsoft Excel® and Endnote® 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 \( S_x \) which is the complete reading of the papers.

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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 (\( \lor \)). 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.

$$S_a = \{ p \in P \mid P \supset \{t_1 \lor t_2 \lor t_3 \lor t_4 \lor t_5 \lor t_6 \lor t_7 \lor t_8 \lor t_9 \lor t_{10}\} \}$$ (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 $\epsilon$ are explained as follow.

At this stage $S_b$ the search terms (from $S_a$) were applied in the three scientific bases in different $\epsilon$ combinations. So $S_b^\epsilon$ is the combination $\epsilon$ 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 $\{t_1, ..., t_6\}$.

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

Where $t_1$ to $t_6$ are respectively thermal, model*, 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).

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

$$S_b^3 = \{ p \in P \mid P \supset \{t_1 \land t_4 \land t_5 \land t_6\} \}$$ (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”.

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6 The asterisk symbol (‘*’) is used as a wildcard, which tells the search engine to replace in that position any other character.
The search $S_b^4$ has returned a total of 162 papers where 87 were from Scopus, 60 from WoS and 15 from IEEEEx.

$$S_b^5 = \{ p \in P \mid P \supset \{t_1 \land t_4 \land t_5 \land t_6\} \land 1 = \text{Eng} \land y \geq 2006\}$$ (6)

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

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<th>Database</th>
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<td>IEEEEx</td>
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<tr>
<td>Scopus</td>
<td>67</td>
<td>50%</td>
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<tr>
<td>WoS</td>
<td>53</td>
<td>39%</td>
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<td><strong>TOTALS</strong></td>
<td><strong>135</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

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)).
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)).

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 - $S_c$

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 $S^1_c$ 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)

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

<table>
<thead>
<tr>
<th>Id</th>
<th>References</th>
<th>Scope</th>
<th>Features</th>
<th>Constraints</th>
<th>IT Approaches</th>
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Source: Authors (2017)
Table 2b: Scope, Features, Constraints, IT Approaches and Methodologies used by the final sample

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Source: Authors (2017)
Table 3: Software used to perform Simulations, Tests and Evaluations

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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\textsuperscript{7} computer system.

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

\textsuperscript{7} https://energyplus.net/
Controls Virtual Test Bed\textsuperscript{11} (BCVTB), DETECr\textsuperscript{12}, IDA-ICE\textsuperscript{13}, PowerDevs\textsuperscript{14} or Yalmip\textsuperscript{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)

\textsuperscript{8} http://www.trnsys.com/  
\textsuperscript{9} http://www.esru.strath.ac.uk/Programs/ESP-r.htm  
\textsuperscript{10} http://www.ansys.com/Products/Fluids/Heat-Transfer  
\textsuperscript{11} https://simulationresearch.lbl.gov/BCVTB  
\textsuperscript{12} http://www.latermotecnica.net/pdf_riv/201309/20130915001 1.pdf  
\textsuperscript{13} http://www.equa.se/en/ida-ice  
\textsuperscript{14} https://sourceforge.net/projects/powerdevs/  
\textsuperscript{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 $S_e$. 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.

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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.


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