Detection and Introduction of Emerging Technologies for Green Buildings in Thailand

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Abstract--**Energy efficiency in Thailand remains low despite the escalating energy consumption. Moreover, Thailand's energy security situation is risky and unsustainable due to its large proportion of energy import and heavy dependency on natural gas for electricity generation. In this paper, a complete citation-based approach employing academic and patent data are utilized in order to detect the emerging technologies for green buildings in tropical countries like Thailand. Data from academic papers and patents are studied simultaneously, and solar cooling has been identified as a promising technology. Solar cooling possesses great potential since it closely fits the environment in Thailand where there is abundant sunlight all year round and air conditioning consumes roughly half of the total electrical usage.**

I. INTRODUCTION

Energy intensity can be defined as the amount of energy used to produce a unit of gross domestic product. The higher the energy intensity means the lower the energy efficiency and vice versa. The improvement of energy intensity in Southeast Asia has been relatively slow as the region was unable to fully extract the available technical potential for energy efficiency while it transformed to more energy-intensive economies. In 2011, the region's energy intensity was more than one-third higher compared to the world's average and twice that of the OECD countries [15].

As for Thailand, it is the second largest consumer of energy in ASEAN, however, it is heavily dependent on energy imports due to the limited energy resources. Oil and gas are imported into Thailand annually and this rising trend is threatening the country's energy security. On the other hand, with electricity being the second largest fuel consumed in Thailand, there is also an urgent need for Thailand to diversify its electricity generation as almost 90% is relied on fossil fuels alone [9]. In 2011, more than half of the energy consumption by economic sector went to buildings whereby 70% of that energy is consumed by ventilation and air conditioning system which accounts for roughly 50,000 GWh per year [25] [24]. Thus, it is critical for Thailand to improve its energy security and energy efficiency circumstances for a more stable and sustaining energy future. Inefficient energy consumption in buildings especially for air conditioning and ventilation represents a sector with substantial prospective for improvement.

A bibliometric approach will be employed in this paper. Bibliometrics refers to a set of approaches to quantitatively analyze bibliographic information of academic literature, patents and other publications. It has been widely used and proved to be a powerful tool for exploring the impact of several factors in a field of research, to detect emerging trends and the direction of research as can be shown in diverse literatures. The author in [16] was able to track emerging research domains in the field of sustainable science effectively and efficiently using citation network analysis despite the overwhelming loads of information in this era. Citation network analysis presents a helpful tool for assisting the planners of energy research and policy makers alike to grasp the wider coverage of scientific and technological research and make decisions on worthwhile investment in promising technologies particularly under resources limitations. Likewise, authors in [29] visualized the overall academic landscape in regenerative medicine as well as detected emerging knowledge fronts and predicted future core papers using citation-based approach instead of the conventional expert-based approach. The author described several shortcomings of the expert-based approach and alternatively presented a computational tool capable of detecting emerging technologies in the stem cell research domain via citation network analysis involving the calculation of within-cluster degree and participation coefficient. The future core papers were predicted via the number of times cited or the betweenness centrality. The method used in [29] focused solely on science publications, therefore even though the results offered an intellectual basis for constructing a strategy for R&D managers and policy makers, they could not guarantee that all emerging fronts possess commercial potentials. On other hand, [4] combined the use of both science and technology databases to testify expert foresights on selected technologies against the results from comparison of the number of publications and patents related to the same technologies for a given year. Trends in innovative activities were predicted through the application of short term forecasting based on technological growth curves. The results suggested that there is a need to combine foresight studies with other tools such as database analysis and forecasting to obtain more in-depth decisions in technology management, research funding, and technological investments. Other methodologies such as scenario planning were also integrated with citation network analysis of patents to anticipate organizational and personal behaviors for a more comprehensive way to detect emerging technologies [7]. Reference [26] compared the structure of the citation network of scientific publications with the patent data to detect areas where one exists but not the other in the field of solar cell.

Areas where there are no patent clusters corresponding to the existing publication clusters suggest potential commercialization opportunities. An expert approach was used in order to compare the topics in the scientific layer to the technology layer and detected the commercialization gap.

It is undeniable that expert foresights are valuable inputs for detecting emerging research fronts, planning of technology roadmaps, and drafting of policies. However, several weaknesses of the expert-based approach have been identified in previous academic studies such as the fact that the amount of academic knowledge is increasing rapidly that it becomes difficult for experts to capture the entire knowledge structure of a specific knowledge domain; the expert-based approach is expensive and time consuming; and the commonly accepted definition of a targeted research field is sometimes missing [29]. Additionally, analysis of scientific publications alone present only one dimension of scientific progress and may not truly depict a comprehensive picture of a research field. Henceforth, this paper attempts to utilize a complete citation-based approach to analyze both the academic and patent data as well as their similarities in order to grasp the overall structure and trend in the domain of green buildings. This methodology in combination with the application of S&T databases proposes a well-rounded strategy for investigation, which is novel and meaningfully differs from formerly deployed approaches. It is expected that the results of the analysis could serve as an initial step for assisting policy makers in solving the energy security and energy efficiency complications in Thailand.

II. METHODOLOGY

The overview of the methodology used in this paper is illustrated schematically in Fig. 1.

In step (1), the bibliographic data of academic papers were extracted from the Science Citation Index Expanded (SCI-EXPANDED), the Social Sciences Citation Index (SSCI), and the Arts & Humanities Citation Index (A&HCI) compiled by Thomson Reuters. Web of Science by Thomson Reuters is the world's leading citation database resource covering more than 12,000 high impact journals worldwide with coverage from year 1900. Key word search was used to search for relevant papers by specifying the following query in the field of topic and title. The results were further restricted to avoid irrelevant papers by excluding the field of Chemistry, Materials Science and Physics.

((eco OR energy efficien* OR low energy OR smart OR sustainab* OR low carbon OR low emission OR green) AND building*)*

In step (2), academic papers data collected from Web of Science are used to construct a network using respective papers as nodes (represented by black dots) and non-directed, non-weighted citation relationships as links (represented by blue lines). Direct citations or inter-citation was employed as it has been shown that it is the most effective method for detecting emerging research fronts as core papers will always be included in the largest component and thus less likely to miss emerging research domains [27]. The three different types of citations are illustrated in Fig. 2. In a case like in Fig. 2, direct citation from P2 to P1 is made at t1 but the co-citation between P1 and P2 is not formed until t2 when P3 cites P1 and P2. Therefore, direct citation analysis is more sensitive to recent citations than co-citation analysis and is superior for detecting changes as early as possible [28]. Consequently, irrelevant papers not linked to any paper in the largest connected components of the citation network were discarded and therefore offering a cleaner and more relevant set of information in step (3). Next, the citation network is grouped into different clusters using topological clustering method [22] in step (4). The topological clustering method is grounded on Newman's algorithm, which is based on the idea of modularity. Modularity is regarded as the quality function to test whether a particular network division is meaningful or

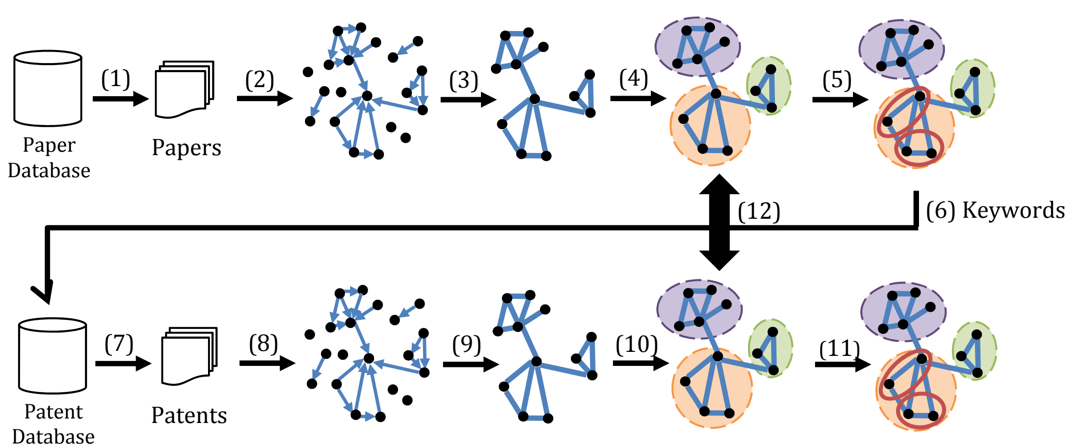

Fig. 1. Overview of methodology

not. In other words, modularity is basically the fraction of edges that fall within communities and subtract by the expected value of the same quantity if edges fall at random without concerning the community structure. The higher the value of modularity signifies the greater significance of community structure. The Newman's algorithm is an agglomerative hierarchical clustering method with the aim to maximize the value of modularity. At the beginning, each vertex is a sole member of a single community, and then communities are joined in pairs repeatedly where the join that results in the greatest increase in modularity is chosen at each step. Newman's algorithm has been employed in many systems to study community structure where the vertices in networks are often seen to gather into tightly knit clusters with a high concentration of within-group edges and a lower concentration of between-group edges. Each cluster was then represented by a name considering their contents as well as the important terms extracted from the highly cited academic papers within each cluster. To aid the visualization, large graph layout (LGL) [1], which is based on a spring layout algorithm is used to visualize the academic landscape. With LGL algorithm, a group of papers citing each other is located in closer positions. For ease of cluster identification, inter-cluster links were hidden and the intra-cluster links for each individual cluster were represented by one uniform color. The characteristics of each cluster i.e. the important keywords, average year of publication and the time series data were investigated and analyzed. Step (1) to step (4) can be regarded as the knowledge-structuring phase where an academic landscape was created in order help us better comprehend the structure and direction of the knowledge domain. Since top clusters generally contain large amount of nodes, recursive clustering, step (5), can be performed on each cluster as to help us understand the topics of individual cluster more in details. When each cluster is divided into subclusters, clusters are trimmed away from the original citation network, that is, each cluster becomes new citation network and the maximum modularity is re-calculated within each cluster. The acquired keywords from step (5) were used as inputs for the patents search in step (6).

The citation network analysis was repeated for the patent data forming a technology landscape. Patent data were collected from the Enhanced Patent Data consisting of Derwent World Patents Index (DWPI) and Derwent Patent Citation Index (DPCI) served by Thomson Innovation. Thomson Innovation offers the world's most comprehensive platform for patent database, covering over 14.3 million basic inventions from 40 worldwide patent-issuing authorities. In step (7), the patent corpus was formed from the database. Similar to the academic domain, from step (8) to step (11), the knowledge-structuring phase was repeated with the exception that for patent cluster analysis, direct citations, co-citations and bibliographic couplings were all selected to create the network landscape since patents tend to have fewer citations than academic papers [26]. A substantial citation network of patents cannot be formed without selecting all three types of citations.

The last step, step (12) involved finding content-based similarities between the clusters of academic papers and patent data. Employing the extracted terms or keywords from each cluster as term vectors, relatedness among clusters can be calculated via semantic similarity. In this study, each keyword in the paper is scored and importance-based cosine similarity was employed to calculate the relatedness between the clusters. In principle, the higher the number of the same keywords clusters have, the more similar they are.

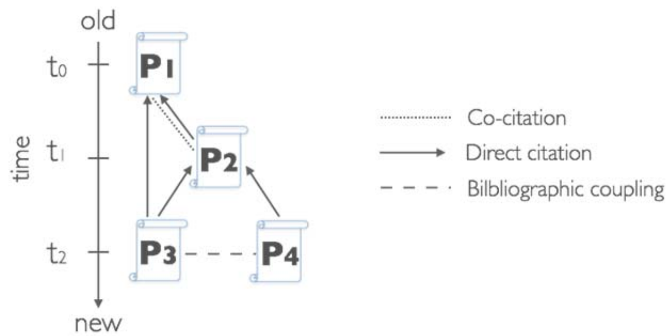

Fig. 2 Different types of citation

III. RESULTS AND DISCUSSION

A. Results of analysis from the science layer

We extracted 27,191 academic papers from Web of Science with the query previously mentioned in the methodology section and 9,070 papers were included in the largest connected component after the knowledge-structuring phase. More than 70% of the papers belonged to the top 6 clusters. The clusters were characterized by analyzing the journals in which the papers are published as well as the related keywords and each cluster was named accordingly. Table 1 lists the keywords and the journals in which the papers were published in for each cluster and the visualization of the academic landscape is shown in Fig. 3.

The biggest cluster (cluster #1) is related to energy analysis and various building environmental assessment methods such as the life cycle assessment. The second largest cluster (cluster #2) discusses the various heating and cooling system available for buildings including the utilization of green roofs while cluster #3 is dedicated to energy efficiency of buildings. The positions of cluster #1, #2 and #3 are close together since their topics are closely related and some citations are shared between these clusters. Cluster #4 examines reef-building corals and their ecologies while cluster #5 deals with social and environmental management such as social-ecological system analysis. Cluster #4 and #5 are isolated from the main connected components, as their topics do not relate directly to the green buildings and this can also be confirmed by inspecting the lists of journals associated with those two clusters. Cluster #4 and #5 are thus

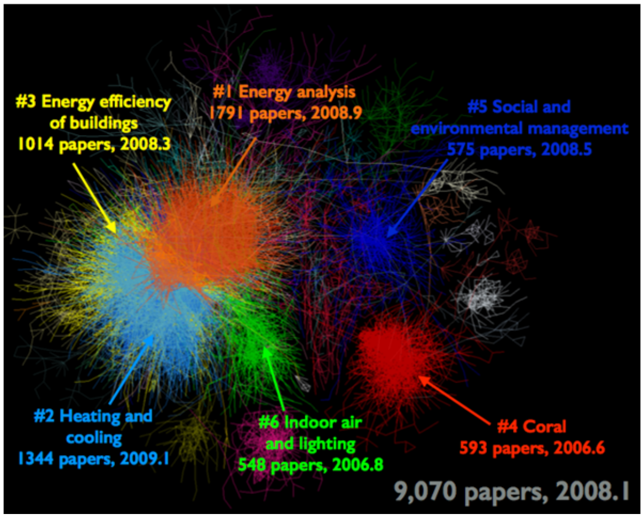

Fig. 3 Academic landscape in the domain of green buildings. The name of each cluster, average year and number of papers in each cluster are mentioned.

excluded from further analysis in this paper. Cluster #6 relates to indoor air and lighting such as ventilation in buildings and natural daylighting.

Fig. 4 presents the results from the time series analysis of cluster #1, #2, #3 and #6 showing the number of publications in each year. It revealed that all clusters exhibit a rapid growing trend whereby the number of publications in these fields is increasing annually despite some minor fluctuations. The trends are quite similar where the number of publications peaked in the late 1990s or early 2000s. The average year of publications in each cluster are relatively young with the youngest cluster being cluster #2 (Heating and cooling) followed by cluster #1 (Energy analysis).

To investigate the detailed structures of Cluster #1, #2, #3 and #6, recursive clustering was performed where these clusters are further divided into subclusters. The recursive clustering results are shown in Table 2. Several emerging research domains can be detected considering from the youngest average year of publications of the subclusters in each cluster. The emerging research fields are design optimization (#1-2), heating (#1-1), life cycle analysis (#1-3), heat pump (#2-1), green roof (#2-2), CHP/CHPP (#2-4), energy benchmarking (#3-5), daylighting (#6-4) and indoor air quality (#6-5).

TABLE 1 TOP 6 CLUSTERS WITH THEIR KEYWORDS AND TOP JOURNALS

Cluster #1			Cluster #2			Cluster #3		
Keywords: life cycle, energy, heating, thermal, energy consumption			Keywords: heat, cooling, thermal, green roof, roof			Keywords: chiller, solar, thermal, cooling, lighting		
Journals	**# papers**		**Journals**	**# papers**		**Journals**	**# papers**	
ENERG BUILDINGS	323	18.0%	ENERG BUILDINGS	338	25.1%	ENERG BUILDINGS	244	24.1%
BUILD RES INF	210	11.7%	APPL ENERG	117	8.7%	BUILD ENVIRON	99	9.8%
BUILD ENVIRON	161	9.0%	BUILD ENVIRON	100	7.4%	SOL ENERGY	83	8.2%
ENERG POLICY	141	7.9%	APPL THERM ENG	77	5.7%	APPL ENERG	77	7.6%
ENERGY	68	3.8%	ENERGY	76	5.7%	RENEW ENERG	55	5.4%
APPL ENERG	51	2.8%	RENEW ENERG	70	5.2%	RENEW SUST ENERG REV	39	3.8%
J GREEN BUILD	39	2.2%	RENEW SUST ENERG REV	69	5.1%	ENERG POLICY	36	3.6%
RENEW SUST ENERG REV	36	2.0%	SOL ENERGY	66	4.9%	ENERGY	35	3.5%
INT J LIFE CYCLE ASS	35	2.0%	INT J ENERG RES	33	2.5%	APPL THERM ENG	33	3.3%
RENEW ENERG	32	1.8%	ENERG POLICY	23	1.7%	J SOL ENERG-T ASME	17	1.7%
Cluster #4			**Cluster #5**			**Cluster #6**		
Keywords: coral, reef, coral reef, reef building, building coral			Keywords: resilience, social ecological, management, social, adaptive			Keywords: indoor, air, indoor air, concentration, formaldehyde		
Journals	**# papers**		**Journals**	**# papers**		**Journals**	**# papers**	
CORAL REEFS	55	9.3%	ECOL SOC	49	8.5%	ENERG BUILDINGS	66	12.0%
MAR ECOL PROG SER	42	7.1%	GLOBAL ENVIRON CHANG	19	3.3%	INDOOR AIR	56	10.2%
PLOS ONE	41	6.9%	OCEAN COAST MANAGE	17	3.0%	BUILD ENVIRON	49	8.9%
J EXP MAR BIOL ECOL	26	4.4%	SOC NATUR RESOUR	15	2.6%	INDOOR BUILT ENVIRON	38	6.9%
MAR BIOL	22	3.7%	ENVIRON SCI POLICY	13	2.3%	ATMOS ENVIRON	37	6.8%
MAR POLLUT BULL	16	2.7%	AMBIO	13	2.3%	ENVIRON SCI TECHNOL	18	3.3%
PALAEOGEOGR PALAEOCL	12	2.0%	MAR POLICY	12	2.1%	ENERG POLICY	10	1.8%
B MAR SCI	12	2.0%	J ENVIRON MANAGE	10	1.7%	SOL ENERGY	9	1.6%
MOL ECOL	11	1.9%	COAST MANAGE	9	1.6%	RENEW ENERG	8	1.5%
LIMNOL OCEANOGR	10	1.7%	ECOL ECON	9	1.6%	J AIR WASTE MANAGE	7	1.3%

From the academic landscape, it can been seen that various aspects of green buildings are being researched covering energy analysis, energy systems, innovative technologies as well as quality of the environment in a building. Building assessment systems and environmental assessment tools are extensively studied such as the life cycle analysis, which is a technique to assess environmental impacts associated with all the stages of a product's life from cradle-to-grave, has been widely applied to buildings in terms of primary energy use and CO2 emission of buildings [14]. Clearly, low thermal energy consumption buildings are desired; nonetheless, the embodied energy of construction materials is also a major concern in the overall environmental footprint [10]. Additionally, it has become necessary for planners to pay more attention to environmental performance in building design and as a result numerous studies are focused on the design optimization of buildings offering different algorithms to evaluate design alternatives under economical and environmental criteria [33].

Since cooling and heating constitutes the largest portion of energy consumption in buildings, many studies are dedicated to the thermal design aspects of buildings. In the recent years, exergy, which is related to the concept of quality of energy, has been rediscovered and consistently applied to new scenarios for energy supply both at building and community levels alongside with energy analysis in order to find the most rational use of energy [32]. Similarly, geothermal or ground-source heat pumps (GSHPs) are also receiving increasing interest as a highly effectual, renewable energy technology for space heating and cooling. A geothermal heat pump can transfer heat stored in the Earth into a building during the winter, and transfer heat out of the building during the summer. Initially, these systems were mostly installed in rural, residential applications where heating requirements were the prime consideration. However, recent improvements in heat pumps units and installation procedures have stretched the market to urban and commercial applications such as the vertical-borehole ground- coupled heat pump (GCHP) technology for applications in air-conditioning [35]. Green roofs and green walls with their benefits of energy saving, pollution reduction, cooling potential are being studied such as the development of appropriate models, analysis of their thermal properties and energy performance or even as a possible tool for solving the rainwater runoff problem in the urbanized 21st century [21], [23]. Likewise, there are a number of studies on small-scale cogeneration or combined heating and power (CHP) technologies. Traditionally CHP plants are large in size and are centralized units, capable of generating both electrical and thermal energy simultaneously. Nowadays, there is a new trend towards small-scale or micro distributed CHP, which is situated closer to consumers and targets for energy production for buildings [2]. Along with the rising demand of air-conditioning world-wide, solar air conditioning has advanced remarkably over the past years resulting from efforts toward environmental protection and continual developments in components and systems, in addition to the notable experience gained from various demonstration projects [3].

In terms of energy efficiency of buildings, energy benchmarking is a relatively young area. Benchmarking energy-efficiency is an essential tool to promote the efficient use of energy in commercial buildings. Different kinds of mathematical methods have been used to develop benchmarking systems, which are then applied to various types of buildings including private offices, hotels, government buildings and laboratory buildings [5], [6], [12], [19].

Numerous researchers are also concern about the impacts on health and wellbeing of building occupants resulting from indoor air quality, ventilation and volatile organic compounds (VOCs). Topics of studies range from building environmental schemes for rating of indoor air quality to health impacts including measurement and evaluation methods of VOC emissions from building products [34], [36]. Another emerging research theme is the reduction of energy use for electric lighting through daylight harvesting. Some studies are related to the benefits of daylighting on humans and their preferred physical and luminous conditions in daylit building environments, while others discuss the techniques to maximize daylighting in building designs such as the utilization of controllable glazing's transmittance to optimize daylighting and building's energy efficiency [13], [18].

Extracting specific keywords from the subcluster analysis as displayed in Table 2 presented a good overview of the range of topics that are being researched and are gaining attention in the domain of green buildings. Subsequently, these keywords were then used as inputs for patents search where two IPC's were chosen to cover the identified keywords. The two IPC's used were F24 and F25, which are related to HEATING; RANGES; VENTILATING and REFRIGERATION MACHINES, PLANTS, OR SYSTEMS; COMBINED HEATING and REFRIGERATION SYSTEMS; HEAT PUMP SYSTEMS respectively. The search query was further refined by specifying "energy AND efficien*" in the text fields.

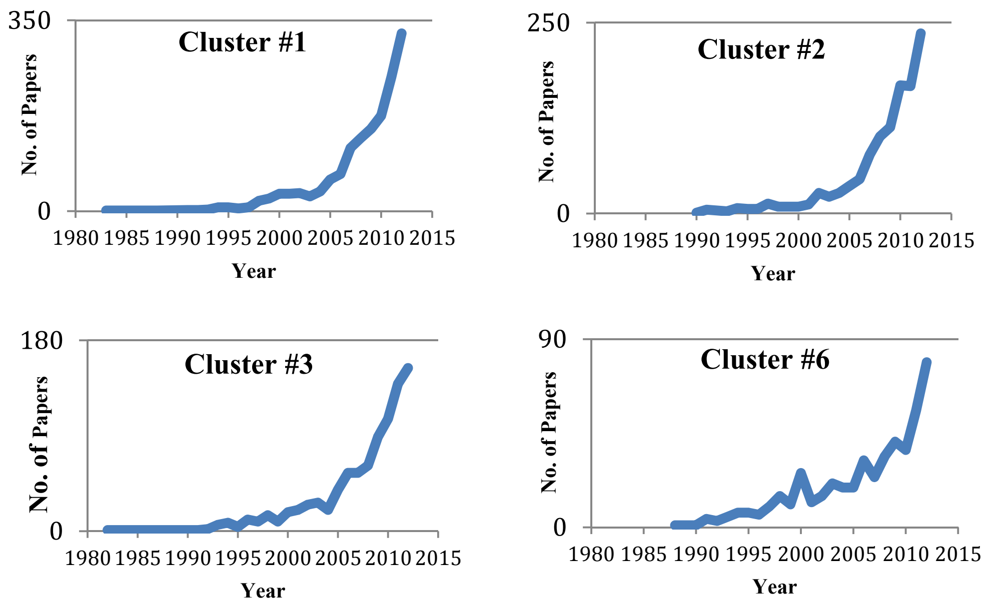

Fig. 4 Time series data of academic papers up to year 2012

TABLE 2 SUMMARY OF ACADEMIC PAPER CLUSTERS AND SUBCLUSTERS

	Cluster name	# papers	Avg. yr	Keywords
#1	Energy analysis	1,791	2008.9	life cycle, energy, heating, thermal, energy consumption
#1-1	Heating	475	2009.4	heating, heat, stock, energy, district heat
#1-2	Environmental assessment	407	2007.6	green building, green, environmental assessment, sustainability, assessment
#1-3	Life cycle analysis	353	2009.4	life cycle, embodied energy, embodied, LCA, cycle
#1-4	Design optimization	270	2009.8	optimization, thermal, genetic algorithm, energy efficiency, building energy
#1-5	Building stock	84	2008.2	stock, demolition, building stock, renovation, deconstruction
#2	Heating and cooling	1,344	2009.1	heat, cooling, thermal, green roof, roof,
#2-1	Heat pump	249	2009.7	exergy, heat pump, pump, heat, ground source
#2-2	Green roof	218	2009.5	green roof, roof, green, thermal, heat
#2-3	Solar cooling	214	2008.8	cooling, solar, cooling system, collector, desiccant
#2-4	CHP/CCHP	213	2009.3	CHP, CCHP, cogeneration, CHP system, CCHP system
#2-5	Phase change material and heat storage	206	2008.7	PCM, phase change, change material, phase change material, heat
#3	Energy efficiency of buildings	1,014	2008.3	chiller, solar, thermal, cooling, lighting
#3-1	HVAC system	155	2008.1	control, HVAC, comfort, predictive, MPC
#3-2	Photovoltaic/thermal solar system	154	2008.2	photovoltaic, BIPV, solar, building integrated, collector
#3-3	Lighting/daylighting	120	2008.3	lighting, daylight, daylighting, illuminance, sky
#3-4	Smart window	104	2007.7	glazing, window, façade, double skin, skin
#3-5	Energy benchmarking	95	2009.2	EUI, hotel, building energy, energy consumption, data envelopment analysis
#6	Indoor air and lighting	548	2006.8	indoor, air, indoor air, concentration, formaldehyde
#6-1	Indoor air quality and health	90	2005.5	indoor, symptom, nasal, ventilation, air
#6-2	Air pollutant	58	2006.5	indoor, formaldehyde, concentration, particle, carbonyl
#6-3	Volatile organic compound	47	2004.7	irritation, indoor, odor, VOCs, air quality
#6-4	Daylighting	42	2009.1	daylight, daylighting, lighting, solar, glare
#6-5	Indoor air quality	42	2008.7	formaldehyde, indoor, VOC, diffusion coefficient, indoor air

B. Results of analysis from the technology layer

The search query for patents returned 24,643 patents and after the network structuring process 4,739 nodes were included in the technology landscape. Fig. 5 and Fig. 6 shows overview of the technology landscape and the time series analysis respectively.

The biggest cluster (cluster #1) of patents is related to solar power system such as the solar tracking technology and it is positioned closely to cluster #6 which deals with the solar collector technology. Cluster #2, #3, #4 and #5 are fairly bunched together and they are associated with air conditioning, temperature and air control, thermal energy storage/cooling system and geothermal and heat transfer technologies respectively.

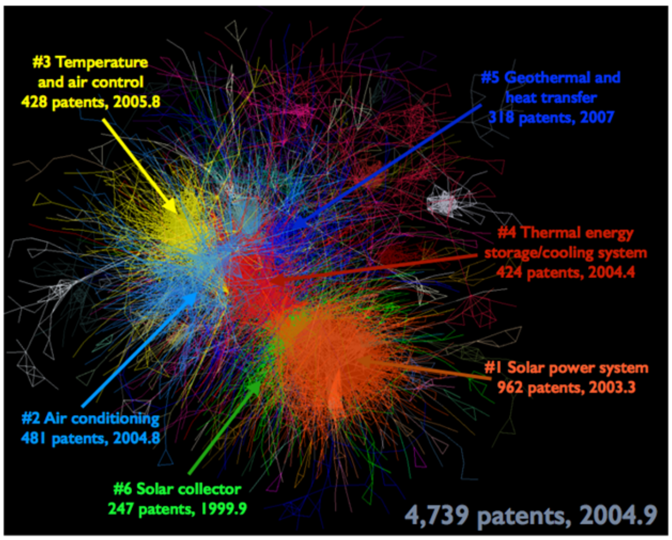

Fig. 5 Technology landscape of patent data. The name of each cluster, average year and number of papers in each cluster are mentioned.

Even though there is not a significant difference in the growth trends of the academic publications, the growth trends of patent publications can be categorized roughly into two groups as shown in Fig.6. Cluster #1, #2, #3, #4, and #5 experienced a gradual increase in the number of patents then more rapidly after around year 2000. However, for cluster #6, the technology seemed to boom in the late 1970s but there was no breakthrough innovation so the booming slowed down until the second booming in the recent years. This pattern may be attributed to the fact that the manufacture of solar water heaters in which a solar collector is one of the main components, began in the early 1960s and the industry of solar water heaters expanded very quickly in many countries around the world [17] causing it to develop and mature faster than other technologies. Subsequently, the numerous developments such as the automatic cleaning function and applications of solar collectors have been further advanced in the past decades, which may have triggered their patent publications to soar once again.

Recursive subclustering is performed on the patents clusters and results are shown in Table 3. Young subclusters of technologies detected are solar tracking (#1-1), heat pump (#2-3), energy utilization control (#3-1), data center (#3-4), refrigerant (#4-4), energy storage system (#5-3), and roof-type solar collector (#6-3). Development in solar tracking technology ranges from the advancement of heliostat orientation controlling method for use in solar power plant to solar tracking sensor and sunlight collecting device. Recent patents on heat pumps components and system controls for efficiency improvement are also observed. In the area of temperature and air control; progresses are made in the field of heating, ventilation and air conditioning data processing and communication network to facilitate system control and

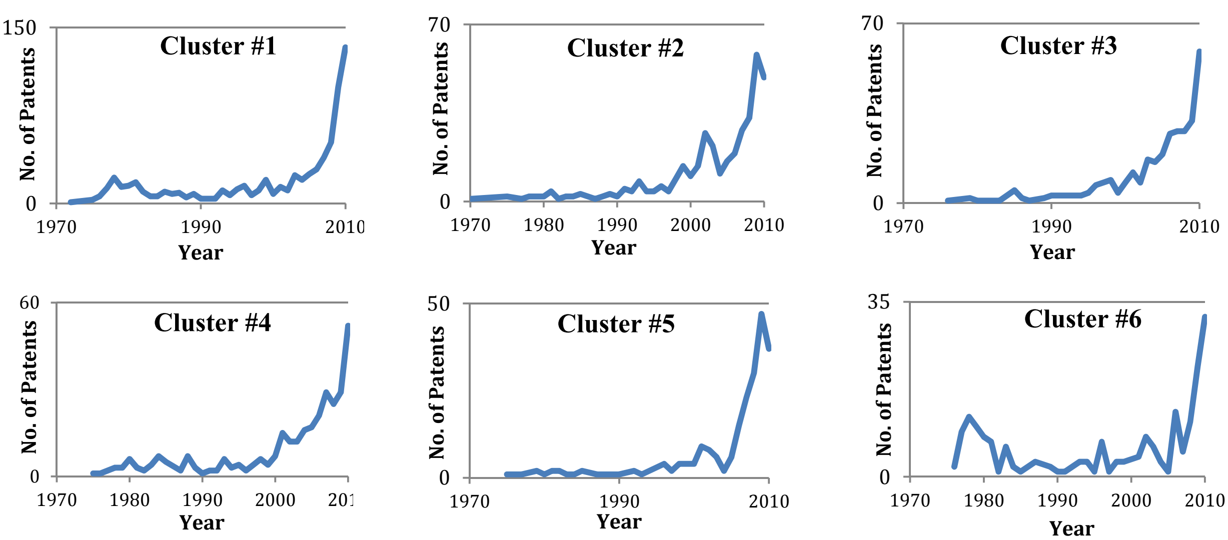

Fig. 6 Time series data of patents up to year 2010

performance evaluation. A number of patents are also related to cooling system and temperature control used in computer data center for effectiveness of distribution of airflow between equipment racks. Developments on various components of refrigeration system such as refrigerant, valve, heat exchange and fin are also underway. Energy storage system is also receiving much attention, as it is usually required with renewable energy systems, examples of development in this field include study of thermoelectric energy storage system and method for storing thermoelectric energy. Last but not least, innovative features of roof-type solar collector include the ice/snow-defrosting device for removing accumulated snow in winter.

TABLE 3 SUMMARY OF PATENT CLUSTERS AND SUBCLUSTERS

	Cluster name	#patents	Avg. yr	Keywords
#1	Solar power system	962	2003.3	solar, solar energy, collector, reflector, concentrator
#1-1	Solar tracking	195	2007.1	solar, heliostat, tracking, solar energy, sun
#1-2	Solar capturing	163	2004.5	solar, photovoltaic, light, solar energy, optical
#1-3	Thermal transfer	137	1996	solar, collector, solar energy, energy collector, absorber
#1-4	Solar energy focusing lens	110	2000	lens, solar, fresnel lens, fresnel, concentrating
#1-5	Solar energy system	108	2004.6	solar, reflector, solar energy, collector, parabolic
#2	Air-conditioning	481	2004.8	air, desiccant, cooling, conditioning, water
#2-1	Desiccant dehumidifying system	77	2001.4	air, desiccant, stream, regeneration, recovery
#2-2	Dehumidifier	61	2004.8	air, dew, cooling, dew point, refrigerant
#2-3	Heat pump	52	2006.2	evaporation part, heat pump, pump, storage, main power
#2-4	Reheater	50	2004.1	air, humidity, reheat, conditioning, control
#2-5	Evaporative air	42	2004.2	evaporative, air, water, evaporative air, warm air chamber
#3	Temperature and air control	428	2005.8	control, air, compressor, temperature, controlling
#3-1	Energy utilization control	79	2008.6	control, air, information, data, conditioning
#3-2	Chiller	75	2006.7	chiller, cooling, compressor, refrigeration, cooling system
#3-3	Sensor and thermostat	46	2002.8	thermostat, control, heating system, temperature, controller
#3-4	Data center	46	2008.7	data center, rack, data, air, computer
#3-5	Air supply control	44	2003.3	control, climate control device, climate control, air, supply fan
#4	Thermal energy storage/cooling system	425	2004.4	water, refrigerant, hot water, air, pump
#4-1	Solar air conditioning system	145	2002.4	water, fluid, solar, hot water, pump
#4-2	Hot water and heat pump	89	2005.1	water, hot water, water supply, water heater, hot
#4-3	Solar-powered refrigeration system	43	2005.3	water, pump, heat pump, water circulation, tap water
#4-4	Refrigerant	41	2007.8	valve, refrigeration, refrigerant, heat exchanger and fin, exchanger and fin
#4-5	Thermal energy storage/cooling system	36	2006.3	storage and cooling system, energy storage and cooling system, load heat exchanger, energy storage and cooling, storage and cooling
#5	Geothermal and heat transfer	318	2007	geothermal, probe, geothermal energy, heat pump, pump
#5-1	Hybrid thermal energy system	40	2006	heat pump, pump, circuit, ground, exchanger
#5-2	Heat exchanger	39	2004.3	geothermal, ground, injector, loop, underground
#5-3	Energy storage system	35	2007.6	energy storage, storing, storage, thermal energy, thermoelectric energy storage
#5-4	Solar and geothermal heat pump	35	2006.5	heat pump, transport circuit, building, pump, collector
#5-5	Geothermal energy extraction	25	2004.8	probe, geothermal, rock, soil, geothermal energy
#6	Solar collector	247	1999.9	solar, collector, layer, solar energy, panel
#6-1	Solar air conditioning devices	37	2001.2	outlet assembly, panel, rib, sealant, roofing section
#6-2	Solar energy collector	28	1998.6	domed, solar, layer, substrate, energy efficient housing
#6-3	Roof-type solar collector	25	2008.2	roof, collector, snow, solar collector, contact
#6-4	Solar collector configuration	24	1991.7	plastic, solar energy collector, energy collector, collector, cover
#6-5	Solar air heater material	21	1990.2	permeable, external side, flowing air, permeable absorber, transparent

C. Results from heat map

In this paper, cosine similarities were calculated and represented graphically by a matrix called a heat map. Rows and columns in the heat map correspond to clusters of academic papers and patents respectively. The gradient of each cell in the heat map signifies the level of relatedness between each pair of cluster where red indicates high relatedness and green indicates low relatedness. The heat map of paper and patent clusters is shown in Fig. 7 considering only the top 10 clusters and results are summarized in Table 4.

Since cosine similarities are based on shared content or the keywords in each cluster; the higher the number of common keywords clusters have, the more similar they are. High similarity between a pair of paper and patent clusters suggests that there has been or will be some transfer of knowledge from the academia to the market, transforming research into industrial applications. The area with the highest similarity belongs to cluster #2 (heating and cooling) of academic papers and cluster #4 (thermal energy storage/cooling system) of patents. Subsequently, in order to understand why these two clusters exhibit such high similarity compared to rest of the clusters, a similarity analysis was repeated for papers in cluster #2 and patents in cluster #4. Results are shown in Fig. 8 and summarized in Table 5.

Among the pair of subclusters, paper subcluster #2-9 and patent subcluster #4-1 exhibit the highest similarity between them, however, since there are only 32 papers in the subcluster #2-9 it may be considered as having a sparse research activity and is therefore of minute interest for our analysis. The pair with the second highest similarity is paper subcluster #2-3 and patent subcluster #4-1 and both represent relatively high activities both in the research and technology applications and their details will be further discussed.

Paper subcluster #2-3 contains 214 papers with the average year of publications of 2008.8. The keywords for this cluster are cooling, solar, cooling system, collector and desiccant. Hub papers that have the highest within-cluster citations are ‘Solar air conditioning in Europe – an overview’ [3], ‘A review for research and new design options of solar absorption cooling systems’ [37] and ‘Energy and economic analysis of an integrated solar absorption cooling and heating’ [20]. After analyzing the contents of papers in the clusters, it can be derived that the papers in this subcluster are related to solar cooling system, solar sorption/absorption cooling system, solar refrigeration system and solar integrated energy system. The countries with the largest number of publications are China, Italy, USA, Spain and France respectively. This result agrees with the fact that many solar cooling related researches are being carried out all around the world and intensely in those countries. The Engineering Research Center of Solar Power & Refrigeration funded by China’s Ministry of Education is devoted to developing new technologies on solar energy utilization together with low-grade thermal energy harvesting such as solar air conditioning systems and comprehensive use of solar energy in energy conservation of buildings. On the other hand, the Solar Air Conditioning in Europe (SACE) project and Promoting Solar Air-Conditioning (CLIMASOL) project are examples of collaborative research efforts in Europe on solar air conditioning [3]. The research of solar heating and cooling has long gained attention on a global scale as can be reflected by the International Energy Agency’s Solar Heating and Cooling (SHC) Programme which was established since 1977. The project’s work is accomplished through the international collaborative effort of experts from member countries and the European Union. Clearly, public funded projects have a prominent impact on academic publications in this field.

Patent subcluster #4-1 contains 145 patents with the average year of publications of 2002.4. Keywords related to this subcluster are water, fluid, solar, hot water and pump. Analysis of the contents of the patents revealed that are applications for solar cooling components, heat pump system, solar air conditioning system, water heater apparatus, hybrid heating and cooling system for building. USA, China, Germany and France represent the countries with highest number of patents respectively. The high industrial activities in the field of solar cooling in the United States can be partly demonstrated by the presence of the Solar Energy Industries Association (SEIA) established since 1974 as the national nonprofit trade association of the U.S. solar energy industry.

After examining the paper subcluster #2-3 and patent subcluster #4-1, it can be concluded that the two subclusters are both related to the technology of solar cooling which represent a promising area not only from the academic perspective but also from the industrial perspective as well. High transfer of knowledge from research to industrial applications suggests that there is a high possibility of realizing this technology for real market applications.

TABLE 4 SUMMARIZATION OF SIMILARITIES BETWEEN CLUSTERS OF PAPERS AND PATENTS

Similarities	Paper cluster and keywords	Patent cluster and keywords
0.4318	#2 heat, cooling, thermal	#4 water, refrigerant, hot water
0.3202	#2 heat, cooling, thermal	#2 air, desiccant, cooling
0.2753	#2 heat, cooling, thermal	#5 geothermal, probe, geothermal energy
0.2721	#3 chiller, solar, thermal	#1 solar, solar energy, collector
0.2576	#3 chiller, solar, thermal	#3 control, air, compressor
0.2394	#3 chiller, solar, thermal	#4 water, refrigerant, hot water

TABLE 5 SUMMARIZATION OF SIMILARITIES BETWEEN SUBCLUSTERS OF PAPERS IN CLUSTER #2 AND PATENTS IN CLUSTER #4

Similarities	Paper subcluster and keywords	Patent subcluster and keywords
0.3567	#2-9 collector, solar, chimney	#4-1 water, fluid, solar
0.3330	#2-3 cooling, solar, cooling system	#4-1 water, fluid, solar
0.3270	#2-1 exergy, heat pump, pump	#4-1 water, fluid, solar
0.1720	#2-1 exergy, heat pump, pump	#4-2 water, hot water, water supply
0.1679	#2-1 exergy, heat pump, pump	#4-4 valve, refrigeration refrigerant
0.1531	#2-1 exergy, heat pump, pump	#4-3 water, pump, heat pump

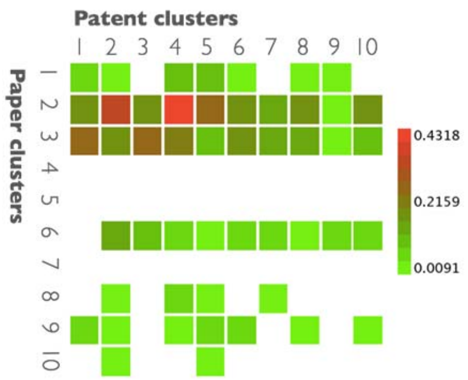

Fig. 7 Heat map showing similarities between clusters of papers and patents

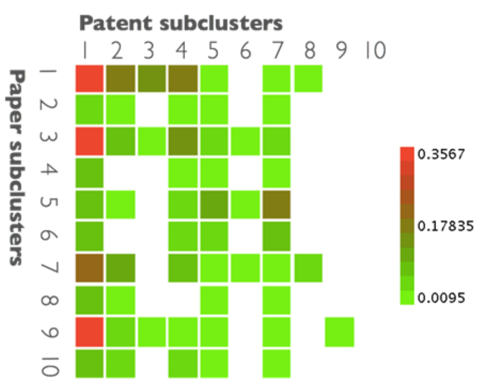

Fig. 8 Heat map showing similarities between subclusters of papers in cluster #2 and patents in cluster #4

D. Discussion of Solar Cooling Technology

Since solar cooling was identified from the similaries analysis of acdemic publications and patents as one of the promising technologies for real applications from both the scientific and technological point of views, its characteristics and prospects need to be further investigate explicitly to confirm its suitability with the circumstances and features of targeted country in this study. Solar cooling or solar air conditioning can be accomplished using thermally activated cooling systems (TACS) driven by solar thermal energy. The system is particularly attractive for tropical countries with abundant sunlight and where air conditioning is required all year round. The two most widely used types are solar absorption systems and solar desiccant systems [30]. Solar cooling offers various advantages over the conventional electric air conditioning since it utilizes the solar energy, it saves electricity and hence primary fossil fuels cutting down drastically on GHG emissions. It is also energy efficient since the cooling load coincides generally with solar energy availability and therefore cooling requirements of a building are approximately in phase with the solar incidence. Employing solar cooling can also helps to ease the load during peak electricity demand benefitting the electricty network and could lead to electricity cost savings. In addition, solar cooling technologies are environmentally safe employing absolutely harmless working fluids such as water or solutions of certain salts. In terms of installation, solar cooling systems can be easily implemented, either as stand-alone systems or with conventional air conditioning, to improve the indoor air quality of all types of buildings. In 2008, there were 81 large scale cooling systems installed and efficiently operated worldwide, with the largest system located in Viota, Greece, with a total cooling capacity of 700 kW and 2,700 m^2 of flat plate solar collectors [31].

Despite the fact that there is a large potential market for solar cooling technology especially in countries with abundant sun exposure, the existing solar cooling systems are not yet economically competitive with the conventional HVAC systems due to high initial investment cost of solar cooling systems and the cheap prices of conventional fuels. Continual efforts to bring down the cost of solar cooling components as well as improving their performance will alter the situation radically. Means and supporting measures are neccesary in order make solar cooling more feasible and accelerate market deployment.

A widespread adoption of solar cooling in Thailand could potentially solve the problem of massive electricity consumption in buildings and relieve the nation's heavy dependence on primary fossil fuels. According to the Renewable and Alternative Energy Development Plan (AEDP 2012-2021), the Thai Ministry of Energy is determined to meet 25% of total energy consumption through alternative energy sources and technology by the year 2021 [8]. Moreover, the Ministry of Energy has set up the 20-Year Energy Efficiency Development Plan (2011-2030), targeting to reduce the energy intensity by 25% in 2030 [11]. The use of solar cooling is mentioned explicitly in AEDP 2012-2021 under the section of renewable heat which states that the installation of solar heating/cooling system installation is to be promoted, possibly starting with pilot projects in government buildings and develop mandatory mechanism such as Building Energy Code requiring large buildings to install solar water heating/cooling system. However, in the recent years, the Thai government has been giving much greater support and attention to solar PV compared to solar thermal/cooling which prominently suppresses the adoption of solar thermal/cooling systems in Thailand. Currently, solar PV installation in Thailand is promoted through Feed-in Tariff (FIT) of 6-7 baht/unit (approx. 200% of the residential electricity price) and the owners can sell electricity to the grid for up to 20 years whereas for solar cooling, there is no government support at the moment. Based on the experiences of Thailand and other countries on renewable energy policies, it is recommended that the Thai government stimulate the growth of solar cooling in Thailand through quality assurance, financial incentives, awareness campaign and demonstration. Capacity building is suggested for Thailand's primary step to quality assurance such as capacity training and qualification of manufacturers, planners and installers. National standards and test center may be the second step towards quality assurance. Solar cooling has a high capital expenditure and low operational expenditure which is opposite to the conventional electric air conditioning [30]. Financial incentives such as subsidy and tax credit can stimulate the market growth particularly during the early stage by helping to offset the higher upfront costs. Furthermore, financial incentives should be long-term and consistent in order to allow customers to make investments under predictable economic conditions. A large number of customers in Thailand are not fully aware of the solar cooling technology, the awareness campaign and demonstration programs could be effective in raising the customer's awareness and attracting more customers.

E. Limitation of methods

Before concluding the paper, some limitations to the methodology need to be mentioned. Firstly, there is a time lag before academic findings or technological outcomes can be published to the public. Moreover, it can take up to two years before a paper/patent receive citations from other papers/patents. There are also limited citations between patents reducing the effectiveness of the network structuring process in capturing the characteristics of the knowledge structure. Integrating the technique of text-mining could be a noble way of tracking emerging patents.

Secondly, our corpus was retrieved from the database via search queries. Some irrelevant data were present but we manually excluded them based on their contents and their segregated locations in the visualized knowlegde landscape. At the same time, the search queries used may not have yielded all the related papers that should essentially be included in our analysis.

Thirdly, citation network analysis is based on the clustering technique to identify technologies. This approach posess a probability of missing isolated papers, meaning that we disregard plausible promising technologies until they have accumulate enough citations and bundle together into a small network. Non-cited influential papers and publications such as non-English papers, conference proceedings, technical reports, textbooks and data sheets were also not taken into account in our analysis. Incorporating a text-based approach, experts' insights and a thorough selection of the corpus may assist to overcome such limitation.

Lastly, although the outputs of our method suggest certain promising technologies with potential for future industrialization, there is no definite assurance of success. The results should be further studied extensively to assess the feasibility and suitable for each country's context.

IV. CONCLUDING REMARKS

Recently, the topics of energy efficiency, energy secuity and environmental problems related to the use of conventional fuel sources have became the primary concerns of policy makers worldwide. Thailand is no exception, its energy security is being threathened by its overbalanced dependency on fossil fuels. Energy used in buildings, especially for hot climate countries where air-conditioning is indispensable made up the biggest share of electricity consumer and therefore represent a sector with significant potential for improvement.

In this work, citation-network analysis was employed in order to detect emerging research fronts and technologies in the domain of green buildings as well as to study the characteristics of the knowledge structures. Databases of academic paper and patent were utilized and similarity study between the two domains suggest areas with high transfer of knowledge from the academia to the industry and a substantial prospect of realizing the technology. Results indicated that solar cooling is one of the promising technologies for buildings efficiency improvement. The benefits and features of solar cooling systems also closely fit the energy situation in Thailand.

It is hoped that the method proposed in this paper would be a useful tool for policy makers to assist them in their initial stage of research and identification of possibles alternatives. Since this research is ongoing, the next step would be to conduct comprehensive scenario planning and feasibility study followed by a more in-depth policy analysis.

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