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A literature survey for electronically dimmable windows: A Perspective of Industry 4.0

Awais S.Kazi, Nikhil R.Shinde, Sumeet S.Mujumdar, Tejas G.Kulkarni

Student, B.E Mechanical Engineering,MCT'sRajiv Gandhi Institute of Technology Juhu Versova Link Road Versova, Andheri West, Mumbai - 400053.

ABSTRACT: In today's era of technology, it has been observed that tinted films are mostly used in domestic applications, and literature survey has identified a significant disadvantage of tinted films that it does not allows sunlight to enter into indoor space and similarly during night, it reflects the indoor light which hampers the occupant's privacy and also creates dull environment. In the winter season, heating of indoor space is desired for increasing human comfort for which sunlight is a major source of heat but due to the characteristics of tinted films, it is reflected. Thesurvey illustrates that tinted films are not useful for maintaining the desired comfort conditions. *(Cuiling Meng Tseng et al., 2019)* identified that the Heating, Ventilation and Air Conditioning (HVAC) system's effect has been reduced due to the use of tinted films in domestic applications. Further literature survey is performed in the domain of Industry 4.0 for considering different techniques which can be used for solving current problems related to Poly-ethylene Terephthalate (PET) windows that are used in domestic and industrial applications. In this study, three existing technologies are surveyed, such as Electrochromic (EC) Polymers, Suspended Particle and Liquid Crystal panels *(Dengteng Ge et al., 2015)*.The mentioned technologies can produce reversible and continuous changes in the optical properties of the film, associated with the phenomenon of ion and electron transport *(C. G. Granqvist et al., 1998)*. It is also found that by varying the film brightness, the intensity of incident light can be controlled in the indoor space. A literature survey revealed some shortcomings in the current research, such as lack of IoT technology for controlling the brightness of window as-well-as heat transfer rate. EC films can be implemented in the sunroof of vehicles, aircraft windows and switchable glasses, which would outperform conventional tinted glasses.

KEYWORDS : Industry 4.0, Electrochromic (EC) windows, advanced automatic control, building energy-saving visual and thermal comfort, adaptive, IoT (Internet of things).

I. INTRODUCTION

Smart windows promise to be the next significant advancement as an energy-efficient technology due to its electrochromic properties, and the ability to change shade without losing sight. The technology reviewed in various papers provides an opportunity to improve and enhance both the energy-efficiency and comfort features of a building through dynamic control and integration with the (Internet of Things) IoT. *[Ali Bahadori-Jahromi et al., 2017]*identifies thatwindows are responsible for a substantial proportion of heat loss in cold climate and solar heat gain in the hot climate (up to 60%). The Glass and Glazing Federation highlighted that up to 40% of a building's load on the cooling system could be associated with solar gain through the windows. Hence, windows built into such spaces should be able to recognize and adapt to the outdoor and indoor temperature as well as the intensity of the input light. The smart windows can either become a part of the Heating, Ventilation and Air Conditioning (HVAC) system or can function as an independent system. The surveyed technologies involved devices with an optimized control algorithm (that takes into account both the energy and visual comfort aspects) with an innovative short-term prediction of incident solar radiation based on a sky-scanner approach and including the user's preferences *[Laura Gonzalez et al., 2018]*. An experimental check was carried out with occupants, allowing the evaluation of the system by the users. In such simulations, different control scenarios were tested against an extended period (one year) and varying meteorological conditions. The simulations allowed for comparison of energy consumption for heating and electric lighting as well as for the estimation of thermal and visual comfort of each case *[Myunghwan oh et al., 2018]*. Tests have also been conducted to identify control strategies that yielded the lowest energy consumption for various climates. In northern

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European countries, where commercial buildings are heat-dominant, passive heating and cooling are frequently fortified. Scholars have investigated alternate strategies with and without daylighting controls where the EC glass is switched into a transparent mode to provide passive heating using sunlight to reduce heat requirements during the winter and cooling during the summer by switching the glass to dark mode. The survey aims to find out technologies that are of great interest in the applications above, which are developed today. Smart windows will eventually have a profound influence on architecture and will lead to new design philosophies.

II. METHODOLOGY

The method for commencing the literature survey included exploring daily life problems, which are usually unnoticed. Various sectors are considered for research where these unnoticed problems were found. Sectors under research are selected as commercial offices, residential buildings, automobiles and production industries. The scrutiny started with a literature survey and discussing with experts in the field. The most prominent step in the literature survey was to select valid search engines, out of several reputed sources available. Four search engines, Taylor and Francis, Science Direct, Google Scholar, Springer are referred based on the keywords. On identifying various keywords, several articles are selected and downloaded from the above-mentioned search engines. Scrutinizing of several articles is done based on objectives, methodologies, future directions and gaps from the papers are identified. The second viewpoint consisted of seeking an opinion from experts and professionals from various fields. A conventional selection was made to enlist experts who satisfied the constraints of research. A questionnaire was developed for having a technical discussion with enlisted experts. Brainstorming sessions were conducted to get the desired levels of output. These outputs were later summarised to obtain the desired domain for research. On the completion of research, certain shortcomings in the existing technologies were found, and inefficiency of the HVAC system was concluded as one of the significant sources of energy consumption which had a scope of improvement. Modern air conditioners provide comfort by maintaining the set temperature at less power, but there is an issue with the power ratings which are observed in the electricity bills. The other problems that were noticed were heat gain and lack of automation. The main focus is to study the list of identified problems. The study was done through the same procedure that included a literature survey through search engines and discussion with experts in the field. The objective of this procedure is to collect information about the source of heat considering a confined space and to identify the sources of heat which are governed by specific parameters. In a particular HVAC system or industry, the significant parameters are found to be occupants, appliances, windows, infiltrating air and walls. The sources of heat were primarily divided into two major characteristics, which are latent heat and sensible heat. Occupants, mainly comprising of humans, animals dissipate heat in the sensible form as well as latent form. Appliances including lights, fans, and electronic gadgets dissipate heat only in the form of sensible heat. Compared to the factors of walls, occupants and appliances, heat transfer through the window is found to be of a higher magnitude. Other factors like infiltrated air and electrical resistances were neglected in the research. It was essential to focus on a single source and to develop a means to reduce the heat transfer rate to a minimum possible value. The criteria for selection of this source were heated transfer rate, cost and feasibility. As heat dissipated by the occupants, walls and electrical appliances are difficult to control, windows remain as the only primary source of heat into the room, which can be controlled. Based on these factors, “windows” are selected as the domain of research from this survey. To study existing technologies that aimed to reduce heat transfer rate pertaining to windows, a similar procedure of literature survey and discussion with experts was performed. Various drawbacks in the technologies have been found while going through reputed journals and articles. Major drawbacks include protection of privacy from the outside world, the brightness of the window cannot be controlled, generic window having only two modes in which it operates and there is a lack of automation.

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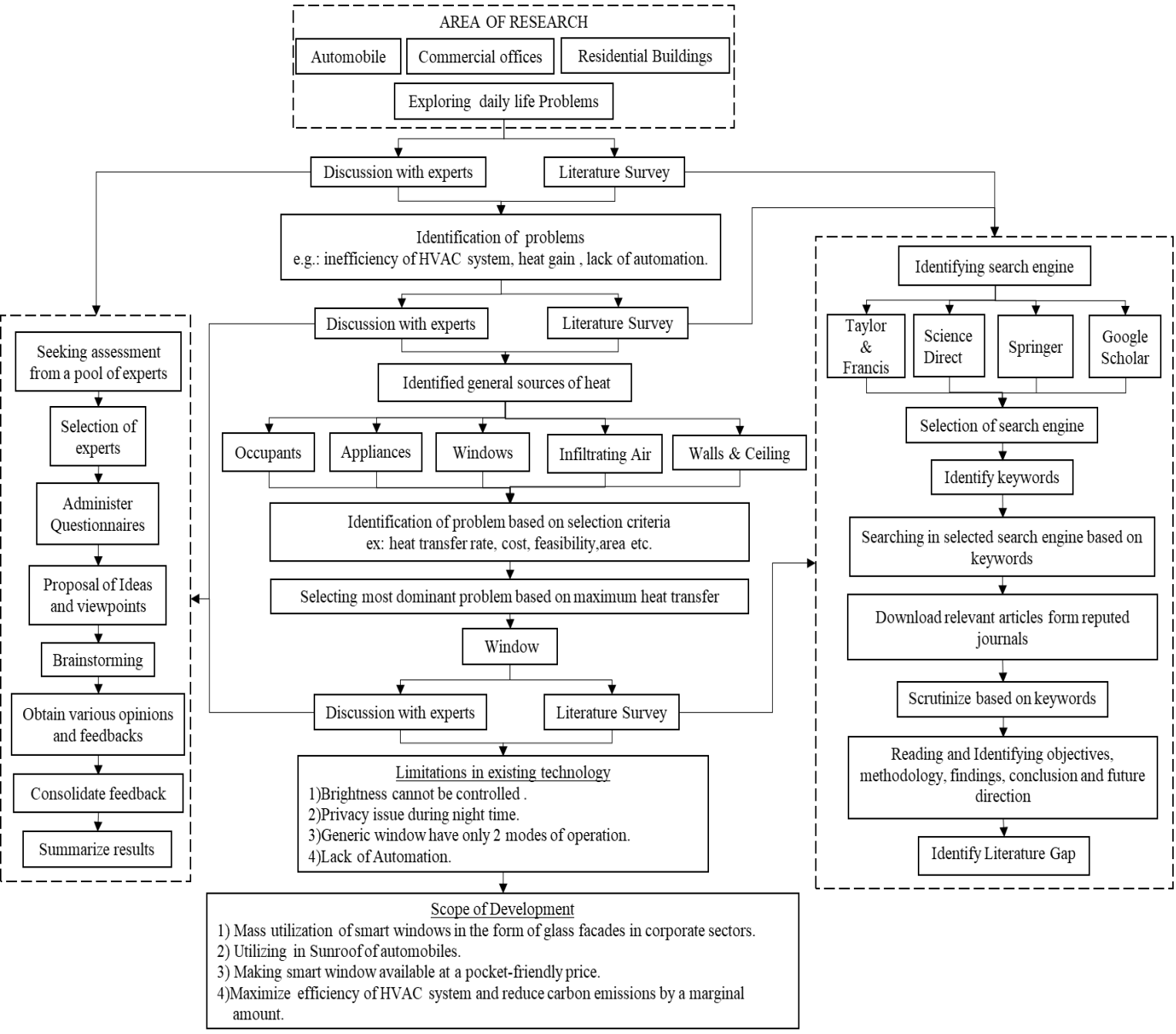
To fill the gaps and remove the drawbacks, the scope of improvement is proposed, which mainly contained the measures to eliminate the drawbacks.

One of the papers surveyed illustrated the following case study: Gugliermetti and Bisegna in 2003 conducted a parametric study to recognize optimum incident solar radiation limits that would yield the least total primary energy. For these simulations, the daylight brightness index was associated with incident auxiliary solar emission levels, then the limits were used to switch the EC windows for visual relief. Overall primary energy consumed was amplified by a



minor margin (4-10%) on the east, south, and west facades and considerably (19%) on the north façade with the visual comfort strategy compared to the best incident solar radiation strategies. These results were given for a moderate-sized window in a typical office for three climates in Italy. The electric lights were dimmed in retort to daylight with photoelectric control panels. When space was unoccupied, the EC was bleached and the lights were turned off. When

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EC windows are fully colored to regulate direct sun and glare, there are adverse effects on daylight levels, lighting energy savings, and room illumination*(Sullivan, Rubin &Selkowitz, 1997) (Mihai Oltean et al., 2006)*. To satisfy visual comfort requirements, windows may require interior or exterior shading devices to block the direct sun. The reviewed study provides an approximate indication of how best to control EC windows given distinctive architectural solutions and the strata of performance that is probable to result.

III. LITERATURE SURVEY OUTCOMES

Sr No.	Title	Authors	Findings	Limitations
1.	Normally transparent smart window with haze enhancement via nonhomogeneous alignment surface.	*Cuiling Meng, Man Chun Tseng, Shu Tuen Tang, Chen Xiang Zhao, Sze Yan Yeung & Hoi Sing Kwok. (2019)*	Increasing efficiency, protection from UV rays, two-mode operation, i.e., opaque or transparent.	This paper does not talk about the variable dimmable feature. Also, the cost of the material is more.
2.	Properties, requirements and possibilities of smart windows for dynamic daylight and solar energy control in buildings: A State-of-the-art review.	*Baetens, R., Jelle, B. P., &Gustavsen. (2010)*	This paper talks about the windows that are adaptable to changing weather conditions, Window alters the cooling loads inside the room, thus increasing the efficiency of the air conditioner.	Glass is adaptable, but it cannot protect the occupants from harmful UV rays, heavy load consumption.
3.	A Review of Electrochromic Windows for Residential Applications. International Journal of Heat and Technology.	*Sibilio, Sergio &Rosato, Antonio & Scorpio, Michelangelo &Iuliano, Giuseppina &Ciampi, Giovanni &Vanoli, Giuseppe & Rossi, Federico. (2016*	Experimental studies piloted on full scale EC windows are analysed, accentuating the measured physical quantities and the applied methodologies making an allowance for both field and laboratory tests. There is an accurate prediction of operating characteristics and optimum design of EC windows.	Further experimental and numerical studies are needed to understand the physical nature of the large area EC windows in order to delineate their actual benefit for manifold operating environment.
4.	BIPV-Powered Smart Windows Utilizing Photovoltaic and Electrochromic Devices	*Rong-Hua Ma and Yu-Chia Chen. (2011)*	BIPV-powered technology shows variation in voltage corresponding to the intensity of incident light.	This paper does not talk about the cost involved and protection from UV rays.
5.	Advanced Control Of Electrochromic Windows	*N.Zarkadis, N.Morel. (2013)*	Advanced automatic control of EC windows, blinds and dimmable fluorescent lights are coupled with the Anabolic Day-lighting System (ADS)	To achieve this automatic control, we need to use a complex algorithm which will increase the cost.

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6.	Impact of Window Films on the Overall Energy Consumption of Existing UK Hotel Buildings	*Ali Bahadori-Jahromi, Abdulazeez Rotimi, Anastasia Mylona, Paulina Godfrey and Darren Cook. (2017)*	This paper illustrates the methods of increasing energy efficiency and its response to changing cooling loads.	The efficiency of this device in a colder climate is out of the scope of this paper.
7.	The Technology For Production Smart Windows	*Ćehić, Minka & Omer, Salah-Eldien. (2018)*	Different techniques which can be incorporated with smart windows resulting in home automation, better energy performance of buildings, environmental protection and energy savings.	The techniques and methods mentioned in this paper are expensive and under research stage
8.	Polymer Dispersed Liquid Crystal (PDLC) "Industrial Technology and Devlopment in Europe"	*H. Hakemi. (2019)*	The two states transparent and opaue by passing electricity through the pdlc film	The high-quality PDLC products for privacy window market, but also to develop new diversified products, such as solar control, bistable, projection screen, direct glazing, dynamic signage and other emerging plastic liquid crystal technologies are still under research and it has been not able to put in domestic use
9.	An electrically light-transmittance-switchable film with a low driving voltage based on liquid crystal/ polymer composites.	*Chunxin Li, Mei Chen, Lanying Zhang, Wenbo Shen, Xiao Liang, Xiao Wang &Huai Yang (2019)*	The PDLC technology and by using electricity,two states are possible that is transparent and opaque.It also illustrates that by using low voltage i.e about 20 volt the change in state is possible	Although this paper talks about the low usage of electricity it does not potrays the information about how variable dimming is possible.It also does not talks about how the process can be automated and used in home appliance
10.	Advanced electro-optical smart window based on PSLC using a photoconductive TiOPc electrode.	*Andy Ying GueyFuh, Shang Yi Chih& Shing Trong Wu (2018)*	Use of TiOPc film, adaptable to changing environmental conditions with the help of smart sensors	Film fabricated by using a variety of high-cost materials, which is not feasible for domestic purposes.

IV. CONCLUSION

An uncontrolled heat transfer rate has been a prominent factor in reducing the efficiency of the HVAC system. To control this, various sources of heat were identified from the literature survey and out of which the window is considered to be a predominant source. Based on this domain, several papers were studied pertaining to the available window technology, where several technologies were figured out and literature gaps were identified. Based on this survey, electrochromic windows seem to be the most promising technology for daylight control.The cost of purchasing tintable windows is quite high, but there can be a scope of improvement in materials, technology and machinery for the

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production of such a device. The use of innovative, smart solutions will reduce the cost of the product, which will promote a more comprehensive application and increase the efficiency of HVAC systems.

V. FUTURE DIRECTIONS

1. The window can be tethered with a mobile application and brightness can be controlled through it by varying the window shade
2. Brightness control can also be automated using advanced IoT enabled sensors.
3. This technology can also be used in the sunroofs and windshields of cars by controlling the sunlight that will enter the car. Thereby improving the efficiency of the automobile air conditioning system and enabling a comfortable drive condition to the driver.
4. Mass utilization of smart windows in the form of glass facades in corporate sectors can be installed, which will provide an amazing aesthetic appearance to the buildings.
5. Making smart windows available at a pocket-friendly price for consumers to relish the advent of home automation at low cost.
6. Maximize the efficiency of the HVAC system and thereby reducing energy consumption by a drastic amount.

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