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A Conceptual Model for Clothes Drying Using Composite Energy Sources

Michael Conyette[1], Olasupo Ajayi[2]
[1]Okanagan College, School of Business
7000 College Way, Vernon, Canada
MConyette@okanagan.bc.ca; OAjayi@okanagan.bc.ca
[2]Okanagan College, Computer Sciences Department
1000 KLO Road, Kelowna, Canada

Abstract **-** Laundering clothes by consumers is paramount for maintaining health and hygiene. Drying of clothes is a crucial part of laundry, and in most developing countries this means spreading clothes on lines to be dried by the sun, or passive outdoor drying (POD). However, due to urbanisation and the proliferation of condos there is little room for sun drying clothes. Additionally, electric washing machines and clothes dryers have become commonplace in many modern homes, however, they consume enormous amounts of energy when drying clothes. Moreover, most families in under-served countries often cannot afford exorbitant electricity bills making these methods to domestic laundry not sustainable. With the continued drive for sustainable living, there is a need for energy conservation alternatives. In other related research work solar energy has been applied in agriculture for drying and preserving food, in electricity and lighting using Photovoltaic (PV) cells, and for heating via radiation. This article explores an alternative for domestic laundry with solar energy, harnessed heat and related technologies. This work does not rely solely on PV cells to generate electrical energy to power heaters, rather we borrow from the food drying process used in agriculture. This entails combining solar concentrators, which focus the sun's energy into a chamber, with a system that channels household heat sources into the same chamber. Within this chamber clothes are hung using smart clothes pegs, which hold the clothes in place. The pegs also measure the moisture level of each garment, then use the telemetry data to control the heat within the chamber. Using these combined systems, enormous amounts of grid electricity and carbon-dioxide emissions can be saved. Actor Network Theory (ANT) and relevant adoption models and theories will investigate consumer adoption and how this technological design is shaped by encompassing socio-cultural factors and physical realities.

Keywords**:** Energy consumption; Energy Recycling; Laundering clothes; Solar concentrator; Solar energy

1. Introduction

Clean clothes can be associated with good hygiene however, the process of removing dirt from clothes through manual hand-washing can be tedious. To this end, washing (and drying) machines were invented. These machines, though helpful, can be detrimental to the environment in general, as they often require a lot of energy to run, hence they are not very sustainable. With the continued rise in global temperatures (leading to extreme weather) and a similar increase in energy-related greenhouse gas (GHG) emissions, as reported in the United Nations' Sustainable Development Goals report of 2022 [1], there is a need to take decisive actions.

Laundering clothes using machines typically includes three major phases – washing, rinsing, and drying. Though washing and rinsing also consume energy, they are not the focus of this paper, as there are numerous published articles on these. Moreover, the past few decades have seen several innovations aimed at improving this phase and making it more sustainable. Some of these include, the use of eco-friendly detergents and soaps which require less water to rinse off, washing with different water temperatures [2] and at varied times of the day [3], and the use of energy efficient (Energy Star rated) washing machines. This work rather focuses on the drying phase of laundry.

Recent studies have shown that the process of drying clothes alone, using electric dryers, accounts for up to 75% of the total energy consumption in laundry processes [2]. According to TopTen.eu, on average an 8kg residential tumble dryer, with an A-class efficient condenser, consumes about 185KWh of energy annually [4]. These figures are approximately the same for both gas and electric dryers, with the former providing only marginal energy savings [5],[6]. Efforts have been made to improve clothes dryer technology, most of which are complementary rather than true alternatives. For instance, certain dryers have moisture sensors fitted in them which measure the moisture content of clothes and adjust the heat levels accordingly. Other dryers first spin the clothes before the drying process begins, while others incorporate a system of heat recovery that reuses the hot air exhausted from the dryer in subsequent drying cycles. The heat recovery system has been reported to yield significant energy savings [6],[7].

Spreading clothes on lines to be dried by the sun, or passive outdoor drying (POD), is possibly the cheapest way to dry clothes. With POD, there are no costs required to run (and maintain) electric or gas powered components. It is also arguably the most sustainable way of drying clothes, with minimal environmental impact and the lowest level of GHG emission. Despite these advantages, POD has several demerits, some of which are: (i) the negative aesthetic of having clothes hanging on lines especially in urban cities; (ii) water dripping from wet clothes might run on the building walls and affect the overall beauty or paint work over time; (iii) the need for open space to run the clothe lines, which is a scarce commodity in urban areas with multi-storey condominiums; (iv) the length of time it takes to dry clothes; and most importantly, (v) the dependence on uncontrollable weather conditions.

Seeing that both technology-based drying solutions (using dryers) and the classic POD both have their demerits, this article proposes a conceptual model for drying clothes that considers the best of both worlds. The model utilises composite heat energy sources to dry clothes. This conceptual model is presented in section 3, right after a review of related works in section 2. In section 4, a discussion on potential consumer adoption of this technological solution is done, while the last section concludes the paper.

2. Related Works

In a Swedish study [8], the authors explored the shift from a communal style of laundry, wherein multiple apartments share a common laundry facility, to in-unit laundry system, where each apartment has its own washing machine and dryer. The article focused on the energy impact of this shift and compared both models from the viewpoints of the number of laundry appliances, energy consumed per appliance use, and how much appliances are used. They concluded that consumer behaviour greatly affects energy consumption. In-unit facilities could encourage frequent laundering, hence increasing energy consumption, however, doing laundry during off-peak hours or using half-load settings could be beneficial. A comparison of energy consumption of different models of clothes dryer was done [5]. The conclusions drawn by the author were that (i) not all dryers are the same; (ii) the remaining moisture content (RMC) was the most important factor that determined energy consumption of dryers; and (iii) the use of moisture sensors within dryers can help reduce energy wastage. In a similar work [6], comparisons were made of three types of clothes dryers – electric, gas, and heat-pump, using various metrics. They concluded that the gas dryer had the highest moisture extraction rate, while the heat-pump dryer was the most energy efficient. Some authors [9] used solar panels to directly power several heater fans installed in a clothes drying cabinet. They reported that the solar powered dryer could dry certain types of clothes in less than an hour. Ambarita, et al. [10] considered the efficacy of a clothes drying cabinet that used waste heat from a residential air-conditioning unit (RAC). They fabricated two types of cabinets – single and multi-inlet and concluded that the multi-inlet was better for drying 6 - 8 kg of clothes. Other researchers have also considered the reuse of waste heat from RACs for drying multiple items including food and clothes, some of which were reviewed in their work [11].

There are various models and theories for explaining how people adopt and accept technologies of various types. Some of these are: UTAUT factors, Davis's technology acceptance model, Theory of Reasoned Action, Theory of Planned Behavior, Innovation Diffusion Theory, Actor Network Theory, Social Construction of Technology theory and others. Many empirically researched models such as TRA, TPB, and IDT have evaluated end users' innovation adoption behaviour. A singular model or theory however may not be sufficient to explain the many variables influencing consumers to adopt the novel technologies described in this paper. A framework consisting of various elements is likely needed to investigate consumer adoption and how the proposed technological design is shaped by physical realities, socio-cultural, and even political factors.

3. Conceptual Model

With the demerits of electric and POD clothes dryers presented in section 1, there is a need for sustainable and economically viable alternative(s). At first glance, a seemingly reasonable alternative might be to consider powering clothes dryers with renewable energy sources, such as solar panel / Photovoltaic (PV) cells or wind turbines; however, energy produced from these sources are transient in nature and not available on demand. Though batteries can be used to store generated energy, the cost implication of installing PV cells and/or wind turbines as well as battery banks capable of powering a clothes washer and dryer system, that can consume up to 5 KW of power, is prohibitively expensive.

As a potential alternative, this paper proposes a variant of the heated drying cabinet. A heated drying cabinet is an enclosed chamber, usually in the shape of a cupboard, within which laundry is hung and air is passed through [7]. The heating cabinet can essentially be considered an enclosed clothes dehumidifier. The application of heating cabinets to dry clothes is not new with many being powered by electricity or reusing hot air from RACs. In this work, we propose the uses of composite heat sources instead of electricity or RACs for our Hybrid Heated Clothes Drying Cabinet (HHCDC).

3.1. Model Assumptions

This work assumes that (i) the proposed HHCDC is to be used in a residential building, probably a bungalow; (ii) the building has an attic space in the roof with easy access to the attic; (iii) the roof has a glass door/window through which sunlight can enter the attic; (iv) hot air would naturally rise to the roof.

It is important to also note that no prototype was built nor were engineering calculations or analysis carried out in this work. This is simply a conceptual model which could hopefully be explored further in the future.

Numerous appliances within a household generate heat. These might include cookers (using any source of heat), pressing irons, a kettle, room heaters, electrical appliances (televisions, computers, incandescent light bulbs, etc.) and even body heat from humans and pets. This heat energy warms the ambient air, causing it to rise up towards the roof attic, essentially making the attic the hottest part of the house and an ideal location to install the HHCDC.

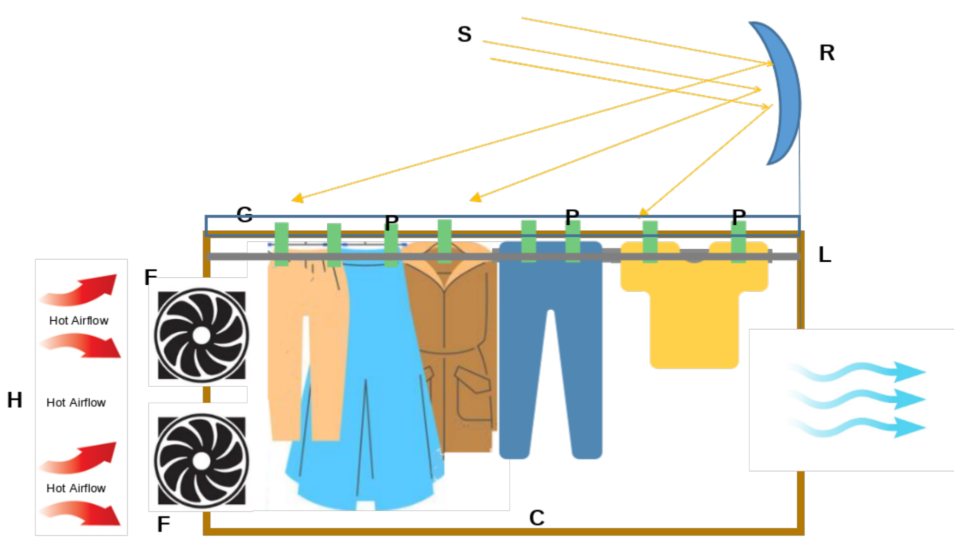

Fig. 1: Layout of the proposed Hybrid Heated Clothes Drying Cabinet

Figure 1 is a high-level depiction of the HHCDC's schematic. In the figure, the primary components of the cabinet are labelled as follows:

H = Hot air in the attic as a result of various activities and appliances in the house. C = An enclosed insulated chamber with a line (L) to hang clothes on. L = Swivelling clothesline that can turn up to 180º ensuring that all sides of the hung clothes are equally exposed to the heat. The swivelling can be achieved using a solar powered servo motor. P = Smart pegs, which serve dual purposes of holding the garments in place and monitoring moisture level to determine when to activate to turn the swivel line (L) and/or switch off the fans (F). F = 5v or 12v fans to pull hot air from the attic into the chamber C. These fans can be powered by a small PV panel or mobile phone charges. S = Sun rays coming in from the glass door / window on the roof. R = a curved reflective mirror acting as a solar concentrator to focus the sun rays (S) into the enclosed chamber C. G = Transparent glass top to allow sun rays (S) into the chamber.

The notion of hybrid as used in the HHCDC stems from the system's use of multiple energy sources. The system uses heated air from composite sources as the primary means of drying clothes and concentrated sun rays as a secondary. By incorporating these alternatives, the HHCDC is impervious to weather conditions and day/night cycle, thus overcoming the major challenge of POD. Furthermore, the fans and the swivel motor (servo), which are the only components that need to be actively powered, have a low energy footprint and can be powered from solar energy or the grid. This small energy footprint gives the HHCDC a significant edge over electric/gas dryers. Finally, the inclusion of smart pegs helps to further reduce the energy footprint and ensures that the clothes are thoroughly dried. This combination makes the HHCDC a potential step in the right direction with regards the concerns raised by the UN in [1].

4. Technology Adoption

This section outlines some models and theories of technology adoption and their components which could be used to build a framework for understanding how consumers may evaluate, purchase and use the clothes drying option presented above. Some of the elements in the framework could include the interplay of consumers' beliefs, attitudes, ease of use, perceived usefulness, prior experience with technology, social support, knowledge and involvement. These elements are described below.

The Technology Acceptance Model (TAM), Theory of Reasoned Action (TRA), and Theory of Planned Behaviour (TPB) impact innovation acceptance and adoption [12]. TRA, TPB and TAM could be used as a theoretical basis to explain consumer acceptance of technology since these models are well known to play a role in adoption [13],[14],[15]. TRA suggests that a person's belief influences his/her attitude. Ajzen [12] describes perceived behavioural control, which was added to TRA in the TPB model, as people's perception of the ease or difficulty of performing a behaviour. This control is claimed to affect behavioural intention and actual behaviour. Research on technology acceptance identified perceived usefulness as the key factor explaining users' behavioural intention [13]. Another researcher [16] in explaining why users accept or reject a particular technology, found that perceived 'usefulness' mediates the effect of perceived 'ease of use' on behavioural intention. Perceived 'ease of use' reflects whether a person feels using a specific system or technology is free from effort. Perceived 'usefulness' on the other hand denotes whether a person believes that using a particular system would enhance his or her performance [17]. Attitude toward using technology is influenced jointly by both perceived 'ease of use' and perceived 'usefulness'.

For our proposed HHCDC, both perceptions should be easily satisfied. The system is easy to operate and requires users to simply open the cabinet door, as they would any normal wardrobe or cupboard, and hang their wet clothes. This simplicity of use addresses the 'ease of use' perception. The 'usefulness' perception has already been long satisfied as dryers were invented to fulfil the need of drying clothes. Our HHCDC can plainly be considered as 'just another type of dryer', that runs on composite energy instead of electricity or gas.

The social support a person receives from friends or family members will arguably increase a person's likelihood of technology adoption. Social support will be perceived as social acceptance. Also, a person's prior positive experience with technology will positively influence adoption [18]. The opposite could be expected with a negative experience and lack of social support.

Prior product knowledge can be described in two different ways, what knowledge the individual has stored in memory (objective knowledge), and what people perceive they know about a product (subjective knowledge) [19],[20]. Knowledgeable consumers are more likely to search for new information before making a decision [21],[22],[23], while less knowledgeable consumers are more likely to rely on attributes such as brand name, price [24] or opinions of others [19],[25].

We jointly consider both prior knowledge and social support because social support starts off from one individual trying out a product to gain insight on it and then telling others about it. Other potential adopters / customers, without prior knowledge of the product, then rely on opinions / reviews of the early adopter(s) to make decisions. In essence, a person is more likely to buy a product they are not personally familiar with, if it has a high number of positive reviews. It only takes a few early adopters to use the HHCDC and give honest and positive reviews about it, for the adoption rate to escalate.

Consumers' perceptions of importance or personal relevance for an object is an indication of their involvement [26]. Involvement is a motivational state that stimulates and directs consumers' cognitive and affective processes as well as decision behaviours [27]. When consumers perceive that a product has a level of personal relevance to them, they are said to be involved with a product and have a personal relationship with it. Cognitively, involvement includes the means and knowledge about important consequences produced by using the product. If product involvement is high, people may express stronger affective responses, such as emotions and strong feelings. Highly involved consumers repeatedly collect information about a product of interest [28].

Lastly, many examinations of technology adoption subscribe to the doctrine of technological determinism whereas this paper considers the larger social, political, and economic circumstances that surround adoption. These are important considerations since among many reasons, sustainability awareness requires different consumption processes. A key researcher [29] supports this notion when he argues that as a new century begins, where the environmental movement is in the lead, technology is now about to enter the expanding democratic circle. Another consideration is that there often is a gap between envisioning technological use and actual implementation.

The rising concerns about increased GHG emissions and global warming in recent years serve as perfect examples of external circumstances that must be addressed. Tackling these concerns would require collective and intentional efforts from the general populace. HHCDC was conceptualised by design to be sustainable through its composite energy model, hence by adopting a laundry solution such as HHCDC, users demonstrate a sense of involvement in the push for a sustainable alternative and awareness of the consequences of an energy irresponsible society.

Countering technological determinism is Actor Network Theory (ANT) which contends that the processes of creating and adopting technology are complex, interactive, and political [30]. Feenberg [31] points out, "technical objects are not things in the usual sense, but nodes in a network that contains both people and devices in interlocking roles". As aptly stated elsewhere [32], "successful technologies must not only get built; they must be built into society". He argues that ANT explains the reason PV systems have failed in the past to gain widespread support; it was due to a struggle involving persuasion and enrollment. Furthermore, Social Construction of Technology (SCOT) theory supports some sentiments expressed by ANT. SCOT proposes that technological determinism is flawed because the exclusively technical is not a determinant in constructing technology [32]. Given the perspectives that ANT and SCOT provide, in order to fully gauge acceptance of the proposed clothes drying process, the framework should include a survey of consumers and relevant stakeholders such as building owners, contractors, electric utility companies, and agencies that establish building codes for their support of the novel process.

5. Conclusion

Laundering clothes, though seemingly mundane, significantly impacts the environment. Clothes drying, using most forms of tumble dryers, consume an enormous amount of energy, yet these dryers are present in almost every home in developed countries. In today's urban cities, the use of passive outdoor drying techniques such as hanging clothes on lines to be sun dried is almost not possible, due to the lack of open space. Besides the absence of space, clotheslines are considered aesthetically unattractive, hence making tumble machines a necessity, despite their long list of demerits. In this work a conceptual dryer based on a heating cabinet and with minimal energy footprint was proposed that is powered by composite energy sources including heat generated from household appliances and solar. The capacity for customer adoption of the proposed clothes drying model was also considered using several adoption models. Though this work only proposed the conceptual model, potential future works might focus on building a prototype and benchmarking it against state-of-the-art drying solutions currently in use today.

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References

[1] United Nations. The Sustainable Development Goals Report 2022. [Online]. Available: unstats.un.org/sdgs/report/2022. Accessed 5th April 2023.

[2] J.S. Golden; V. Subramanian; G.M. Irizarri; P. White; & F. Meier. "Energy and carbon impact from residential laundry in the United States" *J. Integrative Environmental Sciences*, Mar 1;7(1), pp. 53-73, 2010.

[3] L. Godin; S. Laakso; & M. Sahakian, "Doing laundry in consumption corridors: wellbeing and everyday life", *Sustainability: Science, Practice and Policy*, 16(1), pp.99-113, 2020.

[4] TopTen International Group. Energy Efficient Tumble Driers. [Online]. Available: https://www.topten.eu/private/products/tumble_driers. Accessed 2nd April, 2023.

[5] P. Bendt. "Are we missing energy savings in clothes dryers", *ACEEE Summer Study on Energy Efficiency in Buildings*, Aug 15. 2010;20.

[6] X.M. Huang; L.S. Xiong; Y.W. Zheng; H.Q. Liu; Y.Z. Xu; & Y.C. Li. "Comparative investigation of performance of gas dryer and two other types of domestic clothes dryers", *International Journal of Low-Carbon Technologies*, May;16(2), pp. 294-304, 2021.

[7] R. Mould; T. Ramsson; L. Evans; & G. Gibson. "Dryers. Energy Technology System Analysis Programme Technology Brief R09", 2012 June. [Online]. Available: https://iea-etsap.org/E-TechDS/PDF/R09_Dryers_FINAL_GSOK.pdf. Accessed 2nd April, 2023.

[8] L. Borg and L. Högberg. "Organization of laundry facility types and energy use in owner-occupied multi-family buildings in Sweden", *Sustainability*. Jun 16;6(6), pp. 3843-60, 2014.

[9] S. Gunawan; B.M.T. Pakpahan; D. M. Yulanto; L. Atika; & S. Januariyansah, 2022, December. "Performance Analysis of Indirect Clothes Dryer Using Solar Photovoltaic Energy", *in Proceedings of the 4th Intl Conf. on Innovation in Education, Science and Culture,* ICIESC 2022, 11 October 2022, Medan, Indonesia.

[10] H. Ambarita; A. H. Nasution; N. M. Siahaan; & H. Kawai. "Performance of a clothes drying cabinet by utilizing waste heat from a split-type residential air conditioner", *Case Studies in Thermal Engineering*, Sep 1;8, pp. 105-14, 2016.

[11] S. P. Singh and A. Nagori. "Refrigeration waste heat utilization for drying applications: a review", *International Journal of Green Energy*, Sep 1;17(11):pp. 697-721, 2020.

[12] I. Ajzen, "From intentions to actions: a theory of planned behavior", in J. Kuhl, & J. Beckman (Eds.), *Action-control: From cognition to behavior*, Heidelberg, Germany: Springer, pp.11-39, 1985.

[13] V. Venkatesh; M. G. Morris; G. B. Davis; & F. D. Davis. "User acceptance of information technology: toward a unified view", *MIS Quarterly*, 27(3), pp. 425-478, 2003.

[14] W. C. Chiou; C. C. Lin; C. Perng, & J. T. Tsai,. "E-learning usability measurement - using technology acceptance model and usability test", *in Proceedings of the 10th Asia Pacific Industrial Engineering & Management Systems Conference*. Kitakyushu, Japan, 2009, pp. 558-569.

[15] M. Conyette. "Weared Data; the personal and proprietary nature of data on wearable technology devices", *in Proceedings of the Travel & Tourism Research Association Greater Western Chapter (GWTTRA) Annual Conference,* Scottsdale, AZ, 2016, [Online] Available: http://gwttra.com/documents/presentations/2016/Day3/Weared-Data.pdf.

[16] F. D. Davis, "Perceived usefulness, perceived ease of use and user acceptance of information technology", *MIS Quarterly*, 13(3), pp. 319-340, 2016.

[17] Y. M. Huang, "The factors that predispose students to continuously use cloud services: Social and technological perspectives", *Computers & Education*, 97, pp. 86-96 2016.

[18] M. Conyette, "A Framework explaining how consumers plan and book travel online", *The International Journal of Management and Marketing Research*, 5(3), pp. 57-68, 2012.

[19] M. Brucks,"The effects of product knowledge on information search", *Journal of Consumer Research,* 12, pp. 1-15, 1985.
[20] A. Rao and K. B. Munroe, "The moderating effect of prior knowledge on cue utilization in product evaluations", *Journal of Consumer Research*, 15, pp. 254-264, 1998.
[21] G. Punj, and R. Staelin, "A model of consumer information search behavior for new automobiles", *Journal of Consumer Research*, 9, pp. 366-380, 1983.
[22] C. P. Duncan and R. W. Olchavsky, "External search: The role of consumer beliefs", *Journal of Marketing Research,* 19, pp. 32-43, 1982.
[23] E. Johnson and J. E. Russo, "Product familiarity and learning new information", *Journal of Consumer Research,* 11, pp. 542-550, 1984.
[24] C. W. Park and V. P. Lessig, "Familiarity and its impact on consumer decision biases and heuristics", *Journal of Consumer Research*, 8, pp. 223-230, 1981.
[25] D. H. Furse, G. Pun, & D. W. Staelin, "A typology of individual search strategies among purchasers of new automobiles", *Journal of Consumer Research*, 10, pp. 417-431, 1984.
[26] H. E. Krugman, "The impact of television advertising: Learning without involvement", *Public Opinion Quarterly* 29, pp. 349-356, 1965.
[27] J. B. Cohen, "Involvement and you: 100 great ideas", *Advances in Consumer Research*, 9. Ed. Andrew A. Mitchell, Ann Arbor, MI: Association for Consumer Research, pp. 324-327, 1982.
[28] L. Bei, & R. Widdows, "Product knowledge and product involvement as moderators of the effects of information on purchase decisions: A case study using the perfect information frontier approach", *Journal of Consumer Affairs*, 33, pp. 165-186, 1999.
[29] A. Feenberg, *Questioning Technology*. Taylor & Francis, 2012.
[30] M. Mort, *Building the Trident Network: A Study of the Enrollment of People, Knowledge, and Machines*. Cambridge, MA: MIT Press, 2002.
[31] A. Feenberg, "Escaping the Iron Cage: Subversive Rationalization and Democratic Theory" *in R.Schomberg, ed., Democratising Technology. Ethics, Risk and Public Debate. Tilburg: International Centre for Human and Public Affairs,* 1999, pp. 1-15.
[32] B. Sovacool, "Reactors, Weapons, X-Rays, and Solar Panels: Using SCOT, Technological Frame, Epistemic Culture, and Actor Network Theory to Investigate Technology", *Journal of Technology Studies*. Volume: 32 Issue: 1, pp. 4-14, 2006.