Leadership in Sustainable Infrastructure

Leadership en Infrastructures Durables

Vancouver, Canada

May 31 – June 3, 2017/ *Mai 31 – Juin 3, 2017*

EXPLORATION OF PARAMETERS EFFECTING ENERGY PERFORMANCE OF BUILDING

Tabesh, Tofigh [1, 3], Ghorbanalavi, Farrin [2]

[1] Sama Technical and Vocational Training College, Islamic Azad University, Urmia Branch, Urmia, Iran

[2] Department of Environmental Control and Building Technology, Faculty of Architecture, Istanbul Technical University, Turkey

[4] ttabesh@itu.edu.tr

Abstract: The reduction of the effects of global warming has become a priority all over the world. This resulted in the need for reducing the greenhouse gas emissions. As the building sector has the major amount, precautions must be taken in the existing and new building. This paper based on literature review tries to highlight significant factors which effect building energy consumption and to find a proper way in order to increase energy efficiency of the building, reduce running costs and environmental effects. It is considerably achieved that high levels of energy-saving usually can be achieved by optimal combination of several measures, such as exterior heating, ventilation and air condition system, walls, windows, roofs, thermal insulation, and lighting system. The most effective strategies contributing in energy-saving of building design, however, are those applied before construction. As a result, it can be concluded that these strategies can be useful for both the refurbishment of existing buildings and the decision making during the preliminary design stage of new buildings. Thus, it is expected that outcomes of this study would help decision makers and building designer important parameters which effects building energy conservation and environmental concern specifically in early design stages.

Keywords— Building energy modeling; Energy efficient building; Envelope design; Retrofit building.

1 INTRODUCTION

By retrospect to 70's decade oil crisis, energy becomes one of the major topics in agendas of developed and developing countries, which provide their energy needs from others.

Moreover, rapidly growing world energy use has already raised concerns over supply difficulties, exhaustion of energy resources and heavy environmental impacts (ozone layer depletion, global warming, climate change, etc.). According to Oluklulu (2012), during the last two decades, primary energy has grown by 49% and CO_2 emissions by 43%, with an average annual increase of 2% and 1.8% respectively. Certainly, reducing emissions of greenhouse gases and other pollutants, decreasing energy consumption and providing security of energy supply are main global targets against environmental problems. Beside environmental problems, world economy also requires energy savings since economic load of energy use is one of the major actors of the global economy. Energy Efficiency Directive of European Commission (2012), proposed that due to ever-increasing demand for fossil fuels brings ever increasing energy prices, world is forced to use less. All over the industrialized world, the building sector accounts for more than 1/3 of the global energy consumption. Focus on the European situation it is responsible for about 40% of the total energy use for 36% of CO_2 emissions. In that respect, importance of buildings energy consumption became controversial issues all over the world. These data could not be neglected because they directly involve the share of global greenhouse emissions with all its negative impacts on the environment.

2 Literature survey

A probe conducted by Olklulu (2012), revealed that global surface temperature increased 0.4 ~ 0.8°C between the start and the end of the 20th century and the temperature will rise between 1.8 ~ 4.0°C at the end of the 21st century with an increase in extreme events. Climate change is strongly affecting diverse aspects of human society and the natural world. Based on Energy Efficiency Directive of European Commission (2012), the significant warming climate of the whole world due to the global climate change is considered to have strong effects on a building's energy requirement or usage as their heating and cooling needs are related to temperature conditions and weather variations. Many previous studies have concerned the climate impact on building energy usage in recent years. Revealing the impact of climate change on building energy consumption is beneficial for not only making efficient energy saving measures but also reducing pollutant or greenhouse gas emission. In the past decades, buildings designed according to climatic condition which is neglected in our present time. In this study, the climate impacts on extreme energy consumption of different types of buildings are determined and how the climate impact on energy consumption in building was analyzed. Maximum and minimum temperature, solar radiation, type of material, isolation of walls and roofs, climate condition and other parameters are among the factors that affected by our building design process.

2.1 Hot-humid and Mediterranean

A life cycle model was presented to a case study located in hot humid (Antalya) of Turkey by Mangan and Oral (2015). This study focused on implementing effective energy retrofit strategies, thermal insulation and Photovoltaic (PV) systems in terms of improving building energy performance. Then the effect of each measure on life cycle energy consumption and CO_2 emission was determined by using the "Life Cycle Energy (LCE)", and "Life Cycle CO_2 ($LCCO_2$)" analysis. In total, 12 evaluated alternatives were divided into two groups that have been shown in Table 1. The alternative with an optimum performance for Antalya, among the described alternative groups, was A4.

Table 1: The alternatives related to the energy retrofit strategies.

Alt No.	Description	Uwall1 (W/m^2K)	Uwall 2 (W/m^2K)
A1	No thermal insulation layer in the exterior wall components	0.79	3.25
A2	Thermal insulation value = base case	0.37	0.58
A3		0.34	0.49
A4		0.31	0.43
A5		0.28	0.39
A6		0.26	0.35
A7	Thermal insulation value ≥ U value in TS 825	0.24	0.32
A8		0.20	0.25
A9		0.18	0.22
A10		0.16	0.18
A11		0.14	0.17

- A12 Mono crystalline silicon module for terrace roof (190Wp- PV surface area: 148.36 Wp/m^2
- A13 Amorphous silicon module for opaque areas of south façade (340 Wp) PV surface area: 55.30 Wp/m^2
- Turkish Standard -TS 825

Comparing A4 (alternative for Antalya) with A1(no thermal insulation layer in the exterior wall components) showed an increase in embodied energy and embodied carbon values respectively with the ratio of 3% and 1% respectively. By applying PV system, A12 has become the alternative with an optimum performance.

An analysis of the current situation of the public school in Rome was carried out by De Santoli et al. (2014) to identify strategies for energy saving through investigating dimensional, technological and architectural features. In this study, several standard interventions were defined according to the historical and architectural features. By comparing the costs the analysis was performed and parameterized for standard retrofit interventions of the existing envelopes. Benefits achievable by the interventions in terms of energy and money saving were evaluated through a simple payback time analysis (PBT) useful to identify priorities for action. The result showed a total cost save about 0.09 €/kWh. The emerged outcome on investigation of type and quality of the refurbishment and its payback time was led to innovate the problem-solving activities and opportunities. These solutions aimed to gain appropriate standards speedily and consciously, and also avoiding the waste of time and money in the same time[4].

A calculation conducted by Buonomano et al. (2014), focused on energy and economic savings of four hospital buildings. Four strategies were analyzed to improve energy performance (Table 2).

Table 2: Suggested energy efficiency alternatives

Alt. No	Description
CASE A:	Roofs thermal insulation by 3.0 and 8.0 cm of polyurethane.
CASE B:	Installation of a 3-way valve in the buildings substation, suitable for varying the supply water temperature as a function of the external temperature.
CASE C:	Installation of thermostatic valves for each radiator.
CASE D:	Installation of a time-programmable regulation for classroom air heating unit (AHU).

Case D was possibly the most profitable action among the proposed energy saving scenarios determining major savings both during winter and summer operations with a very low capital cost. According to the strict economic point of view, a centralized heating regulation in case B was more profitable than a room in case C.

An investigation conducted by Ascione et al. (2013), focused on varying heating, ventilation, air-conditioning and cooling systems (HVAC) for energy saving by refurbishing thermal- physical features of the building envelope in Mediterranean climates. Impact of envelope renovation on energy demand of three kinds of HVAC system (Table 3) of two buildings envelope was analyzed.

Table 3: The alternatives related to the energy retrofit strategies

No.	Description	Energy Reduction
A1	Fan coil without outside air- HVAC system	2458 GJ (i.e., -50%)
A2	Fan coil with outdoor air- HVAC system	2887 GJ (i.e., -31%)
A3	Air–water HVAC system, with fan coils and dedicated outdoor air system	2945 GJ (i.e., -16%)

Overall, the renovation of the building envelope showed improvement in indoor thermal conditions with regards to all HVAC systems being considered. However, the improvements are more evident for HVAC systems Nos. A 1 and A 2.

In order to evaluate energy performance and the dynamic thermal behavior of the green roof house-holiday building, Gagliano et al. (2014), conducted a survey in Italy using DesignBuilder. The available Energy savings through the introduction of the green roof showed the significant reduction of the total cooling and heating about 80%, 34%, respectively. Furthermore, compared to the traditional roof the green roof provided lower fluctuation of its superficial temperatures, diminishing the average daily temperature fluctuations from 12 °C to 6 °C.

Dogan Sahin et al. (2015), adopting a historical building approach, focused on energy efficient retrofitting (EER) interventions in Izmir-Turkey, with the aim of energy consumption reduction. The alternative which have been considered were weather stripping, Indoor air temperature control, changing the heating system and/or fuel type, insulation of the attic floor, additional insulation to the roof, interior insulation of the walls and additional insulation to the ground floor. Appropriate retrofits were gathered into three packages to evaluate their effects on the energy consumption as shown in Table 4.

Table 4: Energy efficient retrofit packages for the case building.

Alt. No	Description
Package 1:	Without altering the building appearance and damaging the heritage values
Package 2:	Interventions in terms of improving the thermal performance
Package 3:	Some inappropriate retrofits to better understand methodology.

The results show that energy savings of more than 34% can be obtained without damaging the heritage values [8].

2.2 Cold and Continental

Sekki et al. (2015), investigated heating and electricity consumption to find out differences by comparing primary energy consumption. The studied buildings were day care centers, schools and university buildings located in southern Finland and classified based on the construction year. The assessed educational buildings' characteristics were evaluated in terms of volume, heat consumption, energy class, gross area, electricity consumption, heat production, ventilation. These evaluations were based on the actual energy consumption measured to find out both heating and electricity consumption.

Based on the results, differences in energy consumption and primary energy consumption of studied buildings were high and newer buildings consumed less heating energy. For instance, differences between the primary heating and electricity consumption in day care centers, schools and university buildings were 83%, 84% and 76% respectively. However, there was no obvious correlation for electricity consumption.

In order to improve building energy performance, a study conducted by Mangan et Koçlar Oral (2015) in cold climate (Erzurum) of Turkey. Some effective energy retrofit strategies, thermal insulation and PV systems were carried out using life cycle model. "Life Cycle Energy (LCE)", and "Life Cycle CO2 (LCCO2)" analysis-based on life cycle assessment (LCA) method, was implemented to evaluate the effect of each strategy. In total, 12 evaluated alternatives were divided into two groups (Table 1).The alternative with an optimum performance for Erzurum, among the described alternative groups, was A11 (Table 1). As to the PV system application, the alternative with an optimum performance for Erzurum was A12.

In Korea, an on-site survey was piloted by Chunga and Rhee (2014), to find out potential opportunities using the software eQuest for energy conservation in educational buildings. Three groups of building were evaluated. Chosen Energy saving strategies were based on their technical and practical detailed in Table5:

Table 5: Energy saving strategies

Energy classification	Construction year	Parameters	Reduction (%)
New and energy guzzling Old and low-energy Old and energy guzzling	2005-2010 1961-1999 1974- 1991- 1969	Space usage, Age Orientation, Lighting Window area, Shading-device, Heating and cooling equipment	6%–30%.

Strategies such as replacement of windows, reduction of power for lightings, adjustment of indoor air temperature, change in U-value of roofs and walls, automatic standby power cutoff switches were established for buildings. The energy analyses of the surveyed buildings determined the potential for energy conservation in the range 6%–29%. Energy consumption can be reduced in old buildings by10–22%, if windows are replaced and insulation are applied to the building envelope are added. By improving the thermal performance of the envelope, it is possible to reduce energy usage by 18–29 %, while changing the behavior of its occupants.

2.3 Temperate, Maritime Temperate, Temperate - humid

Raji et al. (2015) suggested an envelope design to decrease energy consumption of high-rise office buildings in mild climates. Four significant façade parameters such as window to wall ratio (WWR), glazing, shading, and roof parameters were defined. The effects of applied parameters and their combination were quantified as the percentage of reduction or increase in the total heating, cooling, lighting compared to the reference model. The results revealed that the integration of high-performance design solutions provides a considerable savings in energy by 42%, 64%, and 34% for total energy, heating energy, and electric lighting energy use, respectively.

A comparative study conducted by Han et al. (2015) focused on the accuracy of building energy simulations associated. The methodology focused on the wind pressure coefficients (Cp) measured with computational fluid dynamics (CFD) simulations and building leakage areas. A commercial office building located in Saginaw, Michigan, US was deployed as the framework of study in a case study. In this study four simulation scenarios of infiltration rate have been conserved which are shown in Table 6:

Table 6: Simulation Scenarios

Scenario No.	
Scenari 1	Default setting of infiltration rates in DesignBuilder considering three envelopes tightness levels (leaky, medium, and tight)
Scenario 2	Simulates building infiltration rates using CONTAM (multi zone building airflow and contaminant transport computer program often used for ventilation and indoor air quality analysis) in which data sources of wind pressure loads (simulated by CFD) is Air Infiltration and Ventilation Centre (AIVC) database
Scenario 3	Simulated by CONTAM, input yearly-averaged infiltration rates
Scenario 4	Simulated by CONTAM, input monthly-averaged infiltration rates

The simulation-predicted data of scenarios were compared with the actual utility data and evaluated according to ASHRAE guideline 14-2002. The result revealed that the approximately 12% of the total annual energy consumption (standard deviation: 3.3%) was taken by energy consumption due to air infiltration. The simulations using monthly and yearly inputted infiltration rates, compared to the simulation results associated with default setting and database, had more accurate results [12].The study conducted by Tahsildoost and Zomorodian (2015) examined techniques of energy retrofit and the necessity of appropriate solutions for two school buildings.

Table 7: Building description

Classification	Construction year	Construction year
CASE A	Before 2000	Low quality construction, Non-isolated exterior envelope, Single layer glazing's with metal frame windows
CASE B	After 2000	Only with insulated roof

The procedure contains three steps: first preliminary building performance assessment and presenting retrofit proposals (Table 7), second optimizing and prioritizing scenarios based on energy simulation and payback time (PBT), and third assessment of the implemented techniques. Based on evaluation, 29.87%

and 38.29% primary energy reduction were observed after retrofit implementations in the old and new cases, respectively.

Gul and Patidar (2015) focused on the electrical consumption of an academic building of Heriot-Watt University, Edinburgh, Scotland, adopting a case study approach, to determine the influence of room activities and occupancy in terms of lectures, seminars and meetings on the energy consumption of the building from January 2013 to May 2013. Therefore, daily average electricity consumption, total daily occupancy and daily room activities were considered. An online questionnaire was distributed to staff and students as well as interviews to have a clear view of relationship between electricity and occupancy. The results of the questionnaire indicated that 92% of the building users are visitors. 67% of the respondents were found to use a laptop, 14% use a PC and 37% use a tablet or an IPad. About 6% said that they use an electric kettle and table lamp, 4% use microwave ovens and only 2% use portable heaters.

2.4 Very hot and Hot

To detect operating problems and find out the opportunities for energy conservations (ECOs), Alajmi (2012) focused on energy audit (EA). Sampled building was an educational building in a hot summer climate located in State of Kuwait- Kuwait. A list of issues was identified which were violating the energy conservation principles, such as those outlined in the ASHRAE Standard 100-2006. To measure how much energy could be saved, different recommended effects (HVAC system, Lighting, Plug-in equipment) on building's thermal performance had been simulated using DesignBuilder (DB). In order to assess the feasibility of utilizing the ECOs, the auditor had to calculate the payback period. It was indicated that if all the recommendations had been implemented, 52% of the total energy could be saved. Furthermore, it was found that the CO_2 emission due to electricity use in the building would be reduced by 648 tons per year.

To achieve energy efficient building design, Kocagil and Oral (2015) were set to evaluate design parameters of traditional Diyarbakır houses on heating and cooling loads in Turkey by Design Builder. They evaluated the thermal performance of building forms, generated from traditional architecture, within the defined settlement textures. Each building form, alternatively derived from plan type and A/V ratio combinations. Four commonly seen reference standardized plan type: L-type plan, U-type plan, Inner courtyard plan and central courtyard plan were considered for evaluation.

In this study, the impact of form factor is investigated by six different A/V ratios to determine building form alternatives; 0.50, 0.60, 0.70, 0.80, 0.90 and 1.00. In order to evaluate the impact of the street width and urban blocks on energy loads, four alternative settlement textures (ST1, ST2, ST3, ST4) were defined;

- ST1 and ST2; settlement texture with respectively 6m and 3m street width,
- ST3 and ST4; settlement texture consisted of blocks respectively with four buildings and six buildings

Consequently, building form and settlement texture was found to be influential in heating and cooling loads, and there was a clear correlation between A/V ratio and the heating and cooling loads. By an increase in A/V ratio, the heating and cooling loads increase too. Inner courtyard plan type, among different building form alternatives, was found to need the lowest heating and cooling loads while L type plan need was the highest. On the other hand, ST4, the buildings within the settlement texture alternative, consume the lowest cooling energy, and the reference buildings consume the lowest heating energy.

3 Discussion

For the past 50 years, a wide variety of building energy simulation programs have been developed, enhanced and are in use. An overview of articles provides features and capabilities of major building energy simulation programs. Concerning all kinds of climate condition, building envelope design, energy effective retrofit methods, thermal energy storage (TES) technology and heating, ventilation and air-condition systems (HVAC) are considered the most typical energy-saving techniques. Numerous factors have been affected energy consumption of building. Regarding the literature, the most energy savings are gained by changing heating, cooling, air conditioning and ventilation (HVAC), glazing type window to wall ratio and roof system.

Exploring changes of building energy consumption and its relationships with climate can provide basis for energy-saving and carbon emission reduction. In this study, findings of the previous papers and practical implementations on the total energy consumption are summarized. The most important conclusions are:

- HVAC system can offer great potential for energy conservation when proper control and operation strategies are employed. Based on different climate and building type specific HVAC system were applied in building. For example, countries in harsh hot climate condition like Saudi Arabia and Kuwait, given the heavy reliance on HVAC system to achieve thermal comfort, energy savings of up to 30% can be obtained. However, in humid climates like California evaporative coolers are not suitable and thus are not considered in the optimization analysis for the HVAC system selection. In terms of building type, heating, cooling, ventilation and air conditioning (HVAC) systems are the major part of electrical energy consumption especially at the hospitals.

- In comparison with common roof construction and Green roofs, simulations confirm the effectiveness of the green roofs in reducing the energy needs for both cooling and heating respectively of about 80 and 34%.

- The effect of window size on building energy consumption is investigated for different values of window-to-wall ratio (WWR). As the window-to-wall ratio increased, it resulted in a tendency to increase the variance of heating demand in winter and cooling in summer. For a high-performance envelope (low U-values for opaque parts and for glazing) in a heating dominant climate, energy-saving for different window-to-wall ratio (30%, 50%, 80% and 100%) is highest when the WWR is around 50%, which is the right balance for reducing heat transmission and increasing solar heat gains in winter. Based on the simulation results resulted from studies showed that for lower values of WWR, a higher percentage of energy-saving is achieved for both cooling and heating; meanwhile, energy use for electric lighting increased slightly compared to a fully glazed façade

- Selecting a glazing for window system is crucial which offers a balance between visual and energy aspects. Window glazing improved optical and thermal properties. Thickness, coating, tinted and spacer between panes are important parameters for determining thermal and daylight aspects of the glazing. Results that outcome from studies showed that replacement of windows, by adopting low-emissive glass, photo-chromic or electro-chromic glass and lower U-value would doubtlessly reduce the heat losses. For example, electrochromic glazing has one of the best overall energy performance among the glazing type and shading strategies with considerable energy-savings for lighting (16.9%) and cooling (11.3%) and a total energy-saving of around 1%. Static glazing offered fixed thermal and optical properties while dynamic glazing was considered more advanced due to its switchable thermal and optical properties. Out of all dynamic glazing, electrochromic glazing is the most popular, and its performance was widely investigated by researchers. Thermotropic windows may be less popular, due to its visual provision, but their thermal performance have been confirmed by the researchers.

- Energy reduction and cost reduction in building is more dependent on the amount of glass used in the facilities. Based on studies approximately well-made double and triple glazing can reduce cooling and heating costs by as much as 5–10% and 7.31% respectively.

- Based on literature review, generally, as the orientation was changed from north (N) to south (S), the heating demand decreased and the cooling demand increased.

4 Conclusions

The increase of energy consumption and CO_2 emissions in the built environment has made energy efficiency and savings strategies a priority objective for energy policies in most countries. Scientist across the world is working on energy modeling and control in order to develop strategies that would result in an overall reduction of a building's energy consumption. In that respect, this paper analyses available information concerning energy consumption in buildings related to heating, cooling and lighting.

Numerous studies for various building types located in different climatic regions have been reviewed. It is concluded that the most effective strategies contributing in energy-saving of building design, however, are those applied before construction. Moreover, based on literature review, it seems that retrofitting of building is a reasonable act for increasing energy efficiency of building.

The development and improvement of the HVAC system section of the building consider the most important factors for efficiency requirements presented in literature. In this case, simulation tools for energy use estimation seem to be the best choice. With the demand for thermal comfort, HVAC systems (and its associated energy consumption) have become an unavoidable asset, accounting for almost 50% the energy consumed in buildings.

In addition to great emphasis of HVAC system, building envelope plays an increasingly crucial role in energy reduction. Among all features of the building envelope, effectiveness and efficiency of glazing types is remarkable. One of the strategies of energy efficient building design is the inclusion of daylighting and/or the natural lighting into the building design.

Using simulation programs to solve the complex relationships between climate, occupancy requirements, mechanical and electrical systems, energy-efficiency issues and design characteristics is a strong way of coping with these problems. Designbuider and EnergyPlus are used most-widely among other simulation tools.

References

Alajmi, A., *Energy audit of an educational building in a hot summer climate.* Energy and Buildings, 2012. **47**: p. 122-130.

Ascione, F., Biancoa. F., De Masi. R.F. and Vanoli, G.P, *Rehabilitation of the building envelope of hospitals: Achievable energy savings and microclimatic control on varying the HVAC systems in Mediterranean climates.* Energy and Buildings, 2013. **60**: p. 125-138.

Buonomano, A., Calise, F., Ferruzzi, G. and Palombo, A., *Dynamic energy performance analysis: Case study for energy efficiency retrofits of hospital buildings.* Energy, 2014. **78**: p. 555-572.

Chung, M.H. and Rhee, E.K., *Potential opportunities for energy conservation in existing buildings on university campus: A field survey in Korea.* Energy and Buildings, 2014. **78**: p. 176-182.

De Santoli, L., Fraticelli, F., Fornari, F. and Calice C., *Energy performance assessment and a retrofit strategies in public school buildings in Rome.* Energy and Buildings, 2014. **68**: p. 196-202.

Energy Efficiency Directive of European Commission ; Available from: <http://ec.europa.eu/energy/efficiency/buildings/buildings_en.htm>, date retrieved 01.12.2012.

Gagliano, A., Detommaso, M., Nocera, F. and Patania, F., *The retrofit of existing buildings through the exploitation of the green roofs–a simulation study.* Energy Procedia, 2014. **62**: p. 52-61.

Gul, M.S. and Patidar, S., *Understanding the energy consumption and occupancy of a multi-purpose academic building.* Energy and Buildings, 2015. **87**: p. 155-165.

Han, G., Srebric, J. and Enache-Pommer, E., *Different modeling strategies of infiltration rates for an office building to improve accuracy of building energy simulations.* Energy and Buildings, 2015. **86**: p. 288-295.

Kocagil, I.E. and Oral, G.K., *The effect of building form and settlement texture on energy efficiency for hot dry climate zone in turkey.* Energy Procedia, 2015. **78**: p. 1835-1840.

Mangan, S.D. and Oral, G.K. *A Study on Life Cycle Assessment of Energy Retrofit Strategies for Residential Buildings in Turkey.* Energy Procedia, 2015. **78**: p. 842-847.

Oluklulu, Ç., *A research on the photovoltaic modules that are being used actively in utilizing solar energy, sizing of the modules and architectural using means of the modules.* MSc, Gazi University, Ankara, Turkey, 2001.

Raji, B., Tenpierik, M.J. and Van Den Dobbelsteen, A., *An assessment of energy-saving solutions for the envelope design of high-rise buildings in temperate climates: A case study in the Netherlands.* Energy and Buildings, 2016. **124**: p. 210-221.

Sahin, C.D., Arsan, D.Z., Tuncoku. C.C., Broström. T. and Akkurt. G.G., *A transdisciplinary approach on the energy efficient retrofitting of a historic building in the Aegean Region of Turkey.* Energy and Buildings, 2015. **96**: p. 128-139.

Sekki, T., Airaksinen, M. and Saari, A., *Measured energy consumption of educational buildings in a Finnish city.* Energy and Buildings, 2015. **87**: p. 105-115.

Tahsildoost, M. and Zomorodian, Z.S., *Energy retrofit techniques: An experimental study of two typical school buildings in Tehran.* Energy and Buildings, 2015. **104**: p. 65-72.