The Impact of Airtightness on Energy Conservation of Conventional Cypriot Detached Houses

Yashar Mohamadi and Seyed Vahid Mirnoori

***Abstract*—It is well acknowledged that construction industry suffers from drawbacks of poor construction implementation. Airtightness for instance, is one of the prominent factors which contribute to excessive building energy consumption, in the operation phase of the project. The aim of this research is to demonstrate the disadvantages of low-quality construction implementation from the airtightness point of view, in the early design stage by integrating Building Information Modeling and thermal performance modeling, taking conventional detached single-family dwellings in Cyprus as the case study. Different rates of air change per hour in the insulated and uninsulated residences were considered and, as a result annual energy consumption of an insulated residence which ACH rate was 2.5 – that accounts for poor implementation - computed to be roughly the same as a similar uninsulated case which ACH rate was 0.25 (29942 kWh compared to 30075 kWh). In addition, cooling load demand remained steady at approximately 25000 and 20000 kWh for uninsulated and insulated cases respectively, under the effect of altering ACH rate.**

***Index Terms*—Airtightness, building information modeling, construction implementation quality, ecotect, revit, thermal simulation.**

I. Introduction

Reference [1] performed a statistical study on energy consumption profile of the residential sector in Cyprus, examining 482 dwellings and reported that more than 50% of residences use double-glazed windows. This is obviously to benefit from the thermal insulation characteristic of these elements while, the construction implementation quality is comparatively low that the industry suffers from airtightness problems. Consequently, heat is easily transferred between interior spaces and outside consequently; which according to a study by [2], is susceptive to extreme energy demand "because of the need to condition the infiltrating air". It is concluded by [3] that airtightness is noticeably affected by supervision and workmanship quality, as well as number of building's stories. In fact, the expected energy saving by applying insulation to building envelopes is possibly abated by the airtightness problem as a result of low-quality construction implementation. The current knowledge about the effect of airtightness is generally based on some empirical investigations, taking several existing buildings as case studies in different countries and milieu but, no attempt has been made to project airtightness effects in the early design stage.

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Furthermore, Building Information Modeling (BIM) provides us with more realistic image of the construction implementation and improves the correlation of the pre-design and post-design stages of construction projects. However, the impact of poor implementation cannot possibly be projected. Therefore, the employment of other simulation methods, such as thermal simulation engines and, the integration of such tools with BIM, highlight areas which needs more precise consideration in order to enhance project performance in the operational phase.

Current study aims to predict the drawbacks of airtightness issue as a result of low-quality construction implementation, to the energy consumption - heating and cooling load - of Cypriot dwellings, preceding construction commence using BIM. A comparison is made between conventionally constructed dwellings and the insulated ones with diverse rates of air change per hour.

II. Background

A number of investigations have mentioned infiltration as one of the most important contributors to the superfluous energy consumption in the existing buildings. [4] analyzed United Stated office buildings and found that the infiltration accounts for 13% and 25% of heating load demand in old and recent US buildings respectively while, this share for cooling load demand in both cases was 3%. The impact of unrestrained air change on the "ventilation heating energy" is reported to be significant by [5], causing more than 50% loss in this type of heating energy. [6] studied the effect of different factors on the infiltration rate, as well as the impact of infiltration rate on total energy demand of detached houses of Finland. It was concluded that 15-30% of energy is consumed as a result of infiltration. They also declared that airtightness and annual infiltration rate is correlated linearly. More temperature fluctuation as a result of higher leakage rates is reported by [7], investigating the effect of airtightness on thermal comfort characteristics of buildings. [3] investigated Estonian buildings and concluded that near 60% of buildings do not meet the airtightness requirements of Estonian construction standards using infrared cameras and smoke detectors. [2] performed a statistical analysis of 70000 leakage areas in residential sector of United States and mentioned construction date and building areas, as the most important factors of air leakage anticipation, in single-family detached dwellings.

The most proper thermal insulation material for residential buildings in hot and humid regions reported to be polystyrene, considering the availability, performance and, expense by a large volume of published researches. In China, considering both cold and hot regions represented by Changsha, Shanghai, Chengdu and Shaoguan, analysis was performed on 5 insulation materials comprising foamed polyurethane, foamed polyvinyl chloride, expanded polystyrene, perlite and extruded polystyrene by [8]. As a result, the optimum insulation thickness was computed between 0.053 to 0.236 m and the most eminent material was polystyrene due to the most saving and shortest payback period. Another research for the same city is done by [9] which proposes adding 10 cm of extruded polystyrene facing indoor to external walls of high-rise apartments which along with some other modification (Glass, wall color and shading) will lead to a reduction of 31.4% in cooling load. [10] concluded that wallmate is the best choice amongst fiberglass, wallmate and polyethylene foam, for hot regions like his case study Qatar but, since it is a comparatively expensive material, others might be preferred. Trying to achieve desirable combination of wall type and insulation material, [11] found the most economic choice for wall, stone/brick sandwich wall and 5.7 cm expanded polystyrene as the insulation material, which leads to 58% of saving applying Complex Finite Fourier Transform method. [12] computed the thickness of 4.8-16 cm for Riyadh region, Saudi Arabia and polystyrene as insulation material. [13] suggested that it is more economical to base the optimization on the cooling load in warm regions since the thickness of polystyrene as thermal insulator calculated less for heating degree hours(HDD) than cooling degree hours(CDD). The same method has been used for the determination of optimum insulation thickness by [14] and [15] considering polystyrene as thermal insulator. Similar investigation is performed by [16] and [17]. [18] compared five common building insulation materials (Polyurethane/Polyisocyanurate-Foam, Fiber Glass-Rigid Board, Polystyrene-Expanded, Fiber Glass-Blanket, Polyethylene-Blanket and Vermiculite) based on their R-Value for 5cm of thickness, giving concrete block as reference and made a comparison of the performance characteristic of a wide range of insulation materials. The initial and operating cost of air conditioning systems is studied by [19] and, a reduction of 22% in the initial cost and 25% and 33% in the running cots of constant-air-volume system and variable-air-volume system is observed in insulated buildings respectively and, the optimum thickness of 4 centimeters Polystyrene was suggested as a result.

III. Methodology

A roughly 110 square meters detached Cypriot house comprising three bedrooms is modeled, based on conventional construction materials by Autodesk Revit, one of the well-known Building Information Modeling tools. The model is then and exported to Autodesk Ecotect, the widely used thermal insulation engine which can be integrated with Autodesk Revit satisfactorily. The export process is carried out using Green Building XML schema which “facilitates the transfer of building properties stored in 3D building information models to engineering analysis tools” [20]. Each defined rooms and spaces in Revit, transformed to individual thermal zones during the export process in Ecotect simulation engine. Two types of dwelling, namely insulated and uninsulated is modeled and diverse rate of air change per hour in a variety of 0.25 to 2.5 ACH is applied to them. Full air-conditioning is applied to all thermal zones except the bathroom subsequently and, the comfort band is set to 22-28 degrees of centigrade for summer and 18-24 degrees of centigrade for winter. Actually, it is not possible to assign different comfort bands for different seasons in Ecotect engine hence, two series of result were generated with aforesaid comfort bands and the desired combination of results and seasons is achieved consequently. For instance, results which were generated based on summer comfort band considered for April to September while, for October to March the second series of results based on winter comfort band is regarded. Adding up the Figs, total cooling load is calculated.

IV. Construction Details

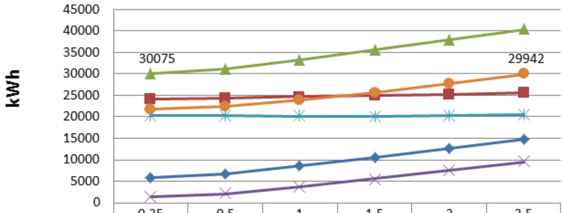
Construction details of the assigned materials to building envelopes in the simulation tool, as typical materials of construction in Cyprus, are discussed below.

For walls, two layers of 10 cm brick with 5 cm of air-gap in between and 1 cm plastering inside, having the U-value 2.62 is chosen. 7 cm of concrete, which outside surface is 5 mm plastered and inside is 15mm carpeted is assigned as floor material having the U-value of 2.56. Roof material on the other hand, is clay tiled roof with 5 cm tiles and 7.5 cm air gap in between and 10 mm plaster layer inside, which total U-value is 3.1. Single-glazed windows are employed for this case.

As the thermal insulation material, 5 centimeter of polystyrene is then added to all elements which altered the U-value factor of each to 1.72, 0.88 and, 1.82 for walls, floors and, roofs respectively. Besides, to achieve more efficient building thermal performance, double-glazed windows were assigned.

V. Results and Discussion

This finding corroborates the results of antecedent researches which, showed that a noticeable share of annual building energy demand is attributed to airtightness problems.



	0.25	0.5	1	1.5	2	2.5
Uninsulated Heating Load	5855	6765	8675	10639	12663	14758
Uninsulated Coolong Load	24219	24365	24664	24960	25228	25540
Uninsulated Total Load	30075	31130	33339	35599	37891	40298
Insulated Heating Load	1419	2133	3743	5551	7490	9521
Insulated Coolong Load	20321	20279	20191	20117	20207	20420
Insulated Total Load	21740	22412	23934	25669	27697	29942

Fig. 1. Annual energy consumption under the effect of the ACH rate.

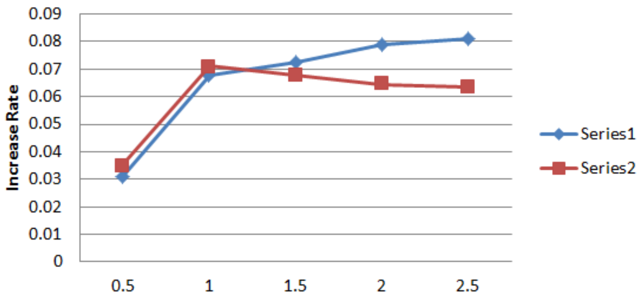


Fig. 2. Increase rate of the total energy demand, based on the ACH rate.

As can be seen from Fig. 1, uninsulated cases reported dramatically lower - more than 25% - annual energy consumption. In addition, what is compelling in this data is that the total annual load demand for insulated case having 2.5 air change per hour (ACH) rate, is quite close to the uninsulated case with 0.25 ACH, having the minor difference of 133 KwH (29942 compared to 30075). On the other hand, energy consumption rose as a result of the increase in the rate of ACH gradually and, the trend was similar in both cases. Surprisingly, the results demonstrate that there was negligible increase in cooling load demand associated with ACH rate that it remained steady at approximately 25000 and 20000 kWh for uninsulated and insulated cases respectively, over one year. In contrast, correlation between heating load demand and ACH rate was strong. It is apparent from Fig. 3, that the increase rate of annual energy demand, interrelates with the rate of ACH as well as building materials since, the rising pace of load demand is comparatively less for insulated buildings however, by increasing ACH to more than 1, the trend is reversed.

VI. Conclusion

The effect of airtightness level is studied in conventional insulated and uninsulated detached single-family houses of Cyprus, integrating BIM and thermal performance simulation. The findings of this investigation highlight the importance of construction implementation's quality assurance, since it contributes to the annual energy consumption of residences significantly.

The following conclusions can be drawn from current research:

1) Total cooling and heating load demand of a residence decreases significantly due to applying thermal insulation materials.
2) As the air change per hour rate is raised in a building, the total energy consumption increases noticeably.
3) Although it is expected that building energy consumption is reduced as a result of employing thermal insulation materials, the unrestrained air change which, is due to low-quality construction implementation, can lead to a surge in building's energy demand that it equates to a similar uninsulated rather well implemented building.
4) The rate of air change per hour has minor effects on the annual cooling load demand.

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