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ZERO ENERGY HOUSE DESIGN FOR CYPRUS: ENHANCING ENERGY EFFICIENCY WITH VERNACULAR TECHNIQUES

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ABSTRACT

This paper analyses the thermal performance of three Cypriot houses with different thermal mass properties. Three houses with different structural characteristics, i.e., Adobe, Stone and Concrete, in Cyprus were selected to collect the actual thermal environment with HOBO data loggers. The investigation will benefit the energy saving of residential buildings in semi-arid Mediterranean climate. Evaluations showed that the Stone house has the best thermal performance and as a result, high thermal mass can reduce the cooling loads significantly in the case of Cyprus.

INTRODUCTION

The Built environment consumes 50% of the world's energy production and Cyprus is no different in this consumption rate as an island in the Mediterranean Sea, which has limited resources of energy and materials (Melet, 1999). This limitation causes the housing sector to use fossil fuels and electricity extensively. In addition, a high percentage of new built buildings/houses in Cyprus do not tend to use local techniques anymore. This pattern is one of the main reasons that the housing sector energy consumption and demand is on the raise. Main problem besides the economic crisis facing Cyprus nowadays is the increasing energy need for achieving comfortable buildings. Recently built new buildings tend to achieve this by relying on artificial solutions, which puts more pressure on the energy demand. However, this problem can become the solution by being smart and using the natural environmental resources. Traditional techniques used in the building design tend to serve as a good starting point for energy efficiency in buildings. This becomes possible with the reduction of the energy demand of the building by using simple passive features that are common and with the integration of new emerging technologies to achieve more efficient built environment in semi-arid Mediterranean climate.

Energy efficient house design tends to require different approach for each location and climate. Vernacular buildings can be a major contributor to the energy efficiency. Energy efficient buildings can simply improve the quality of the built environment. This paper tends to explore and define a new understanding for energy efficient house design for Cyprus. Focusing mainly to combine traditional techniques and zero carbon energy systems. By applying both traditional and new techniques will achieve more energy efficient buildings. This will be analysed and evaluated through the design process by various simulation programmes. With this research, there will be a better understanding of indoor conditions of Cypriot houses temperature behaviour. Moreover, defined thermal behaviour would help to improve comfort and minimise overall energy consumption.

Context and Aims

The case study houses are two story single detached houses. Each house has HOBO data loggers to monitor the thermal conditions. All three houses have households with minimum two constant occupants. In addition, every house has solar thermal panels for hot water heating.
Aims of this paper are:

- Monitor real life thermal performance of each house by indoor data loggers.
- Evaluate thermal performance of each house and user behaviour.
- Calibrate simulation models with recorded indoor HOBO data.
- Analyse and define energy efficient vernacular techniques.
- Devise a set of guidelines for energy efficient houses in the case of Cyprus.

Requirements of Cyprus as an EU Member State

Cyprus as an EU member has to achieve certain levels of energy efficiency in buildings. Also by 31st December 2018 at the latest, EU member states must ensure that all newly constructed buildings produce as much energy as they consume on-site (EU Directive, 2010). The deadlines are also similar for existing building stock and for the EU member states to set intermediate national targets for existing buildings, i.e. to fix minimum percentages of buildings that should be zero energy by 2015 and by 2020 respectively. In addition, the newly built houses have an increasing energy demand for achieving certain comfort levels and recently built new buildings tend to achieve this by relying on artificial solutions.

Climate and Vernacular Architecture of Cyprus

Cyprus is in semi-arid Mediterranean climatic zone, which has a typical Mediterranean climate although there is some little differences can be seen because of its geographic condition where Cyprus can be grouped as hot arid, hot humid and composite. Technology has been a functional adaptation of the making and using tools to both survive in and transform our surroundings (Steele, 2005). Traditional techniques used in building design tend to serve as a good starting point for energy efficiency in buildings. This combined approach has been considered as a form of energy efficient building design and requires an understanding of the climate of the locality hence it can take advantage of its characteristics (Yeang, 2006).

Cypriot vernacular architecture has a long history beginning from the Neolithic age, using existing materials such as stone, earth (adobe) and wood to create shelter. This approach then evolved and become climate sensitive design. In Mediterranean's hot climate where sunshine in winter is rich and cooling and ventilation in summer are required. Solarium courtyards are not a changeable part of vernacular architecture in Cyprus. Passive solar solutions are an instinctive approach in vernacular houses of Cyprus. They concentrate on climatic conditions and requirements of the users and social characteristics (Serghides, 1992). Transitional spaces combine functions to the courtyard with flexible functions.

Vernacular architecture remains same and did not influence from outer factors compared with the urban areas. Providing the basic needs of locals is the main concern of Cypriot vernacular architecture. A typical Cypriot vernacular house consists of a courtyard living and service areas (Ozay, 2006). Orientation is always on south north axis with a semi open arched hall facing south (Dincyurek et al., 2003). Minimum openings on the northern facade are required to block cold northern winds (Dincyurek et al., 2007). In vernacular Cypriot houses, there are a rich variety of open and semi-open spaces, such as open-to-sky courtyards, verandas at the front and sündürmes at the back, all with access to greenery. Existing traditional techniques have infused on the recently developed building materials and systems to enhance energy efficiency.

INVESTIGATION AND CASE STUDIES

Case Selection

In the study, three case study buildings have been selected with different thermal mass properties. First, is Stone, second is Adobe and third one is Concrete construction. All three houses have minimum two occupants. In addition, two of the houses have working families while third has a retired couple. The selected houses are described below from figure 1 to 3.

1. Case Stone House: New building built in late 1990s and has some vernacular influences. Sandstone is the main construction material. Occupants are two in weekdays and five at weekends.

Figure 1 Stone House: street view (left) and garden view (right)

2. Case Adobe House: Vernacular building built in 1940s by empirical builders. It is an example of rural vernacular houses of Cyprus, which relies on cross ventilation and thermal mass for cooling. It has no mechanical cooling system. Adobe bricks are the main construction material with wood floors.

Figure 2 Adobe House: street view (right) and garden view (left)

3. Case Concrete House: New building built in early 2010s with modern materials. There is the use of some vernacular materials as decorations. It was built by a construction company and has double glazing windows. There is no shading and the orientation is east west.

Figure 3 Concrete House: street view

Indoor Monitoring

HOBO data loggers placed in each case house to monitor thermal performance. Loggers have the measurement range of -20° to 70°C where the accuracy is ± 0.53°C from 0° to 50°C. Two loggers placed in each house; one in living room and the other in bedroom.

Thermal Performance Evaluation

Stone House: Correlation of temperature rise is significant at night and in afternoon. There is no correlation of temperature rise at morning and during midday. High thermal mass requires time to transfer heat. There is no one at the house during daytime for weekdays. There is no direct solar gain from windows. There is small amount of correlation at night and in afternoon.

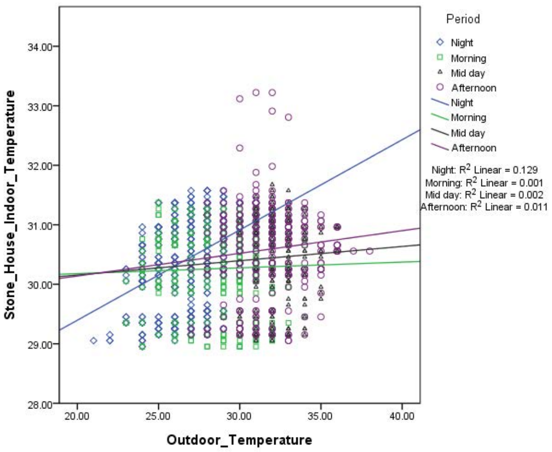

Figure 4 Stone House: Scatter plot for thermal behaviour indicates rare use of natural ventilation at afternoons

Adobe House: Correlation is significant at night, in midday and in afternoon. There is no correlation for morning. Amount of correlation is small at night and in midday. Amount of correlation is medium in afternoon. Thermal mass effect delays the temperature rise. High ventilation occurs all day. This house uses cross ventilation with vernacular methods and techniques.

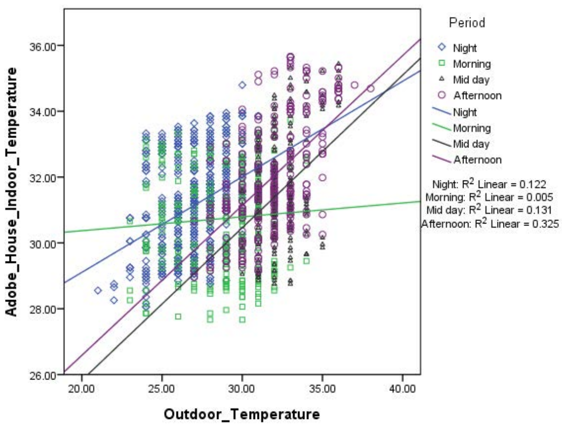

Figure 5 Adobe House: Scatter plot for thermal behaviour shows all day use of natural ventilation

Concrete House: Correlation is significant at night, in morning and in afternoon. There is no correlation in midday. The amount of correlation is small in afternoon and at night. The amount of correlation is medium in morning. West east orientation of the house maximises solar gains in afternoon.

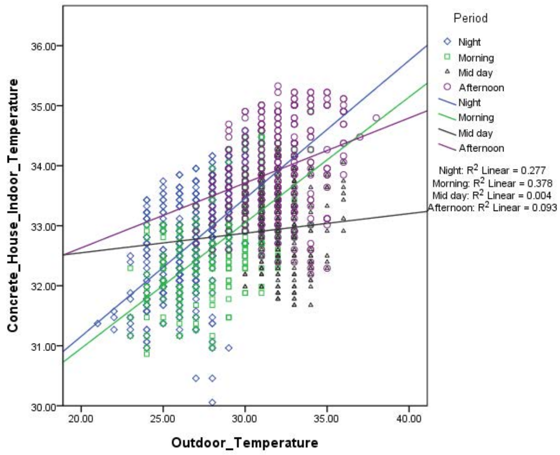

Figure 6 Concrete House: Scatter plot for thermal behaviour reveals nighttime use of air-conditioning

Stone house shows the best thermal performance compared to Adobe and Concrete. Only at night time Adobe house performs slightly better than Stone. High thermal mass proves to control rapid outdoor temperature increase better than others do. Adobe is also a high thermal mass structure but performs slightly different because of its user behaviour and longer period of natural ventilation. Natural ventilation is also the cause that Adobe house performs better at nighttime. Concrete house performs the worst among all cases. Reasons of these are thermal conductivity of the concrete as a material and concrete houses do lack of shading, which causes unwanted direct solar gains. Concrete house is the only case where users rely on air-conditioning to achieve thermal comfort (see figure 6).

Simulation Models

DesignBuilder software programme has been used to analyse the thermal performance of the three selected case study houses (version v.2.1.0.025). Each house modelled by the help of architectural drawings. Two sets of questionnaires used to identify occupant behaviour. The simulation models are shown further below from Figures 7 to 9.

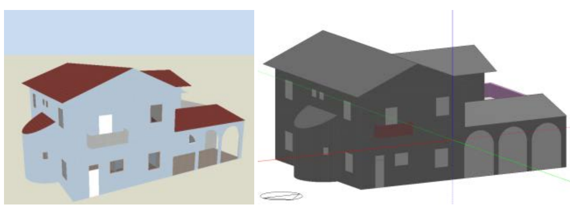

Figure 7 Stone House: DesignBuilder model

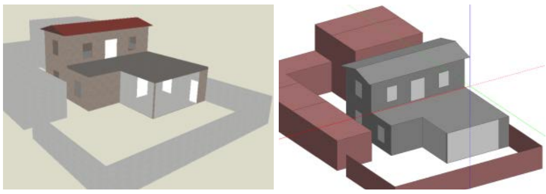

Figure 8 Adobe House: DesignBuilder model

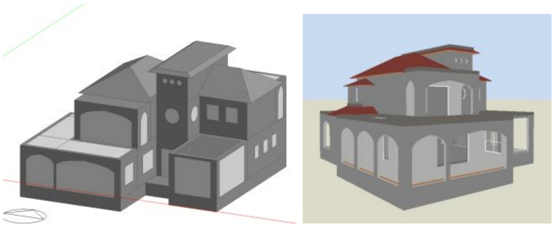

Figure 9 Concrete House: DesignBuilder model

Simulation Process

Case Stone has extensive use of solar shading. This allows the occupants to control direct solar gains when unwanted. In the simulation model, the direct solar gain patterns cannot match with the actual data. This is most visible in the afternoon values from 18:08 to 21:08 (see Figure 10).

Adobe house model do not have the shading limitation, where the stone house has. This advantage led to a very similar temperature pattern in between the actual data and the simulation data (see Figure 12).

Concrete house have similar setback as Stone. Direct solar gain differences are visible in morning and in midday (see Figure 11). Concrete case has the biggest difference in temperature values. Although all the difference is, lower than 15%, further modification can provide better results.

Temperature Validation

The process of temperature validation presented in Table 1. 1st July selected to validate the models for hot season. Percentage of difference equation used to validate the simulation models. a is the simulation temperature and b is the recorded temperature.

$$\%\ \text{Difference} = \frac{a-b}{b} * 100 \qquad (1)$$

All cases have occupants that day. This means that each case operates and the actual data is from an occupied day. This justifies the natural ventilation variable that scheduled in simulation programme is also valid.

The maximum ‘Percentage of Difference’ to accept as valid is 15%. In Stone house’s case, Percentage of Difference is at max 5.59%. Adobe house have Percentage of Difference at max -4.24%. Concrete house have Percentage of Difference at max 11.66% (see Table 1).

DISCUSSION

Simulations were finalised using thermally validated models. Validated models used to test thermal performance, natural ventilation and direct solar gain minimisation. Effect of thermal mass in the case of Cyprus helped to delay and minimise indoor temperature fluctuations. Both simulation and actual indoor data showed that high thermal mass could be very effective in the context of Cyprus. In addition, natural ventilation can minimise the cooling loads substantially.

Shading is one of the main variables to control. DesignBuilder is limited in shading options and it does not allow any occupant controlled method to have full shading when desired. Shading and solar gain variables need to expand options. Without proper shading, direct solar gain can produce overheating especially southwest west directions.

Basing upon the evidences, design guidelines are listed below:

- Use thermal mass effectively to minimise indoor temperature fluctuations.
- Use of passive cooling techniques to minimise cooling loads.
- Cross ventilation can be maximised by the use of small voids to catch breeze and channelling through zones.
- Minimum three layer of shading use to minimise solar gain on both voids and solid surfaces.
- Maximising functionality of semi open spaces can also reduce unnecessary area usage of modern houses.

CONCLUSION

The outcome of this research was to reveal the thermal behaviour performance of different real time Cypriot houses. It is clear that high thermal mass structures perform better in the case of Cyprus. In the evaluated cases, Stone performed better than Adobe because it has better shading and controlled natural ventilation. High thermal mass can reduce the cooling loads significantly in the case of Cyprus.

The study also defines the vernacular techniques to achieve an energy efficient building environments in the case of Cyprus. Moreover, it is aiming to show the possibilities available for various building types according to their needs and to predict the optimum ways of integrating traditional techniques and emerging technologies harmoniously. Summer has the highest energy demand. Especially spring and autumn seasons are more efficient and would need less energy to keep houses in comfort conditions. The study will continue with further analysis to reveal what extent the energy efficiency potentials are in each housing type.

Table 1:Actual, simulation temperatures and Percentage of Difference values.

Date 01/07/2012	Adobe Temperature	Adobe Design-Builder Temperature	Adobe Percentage of Difference	Stone Temperature	Stone Design-Builder Temperature	Stone Percentage of Difference	Concrete Temperature	Concrete Design-Builder Temperature	Concrete Percentage of Difference
00:08	29.55	28.38862	-3.93022	29.45	29.01183	-1.48784	31.88	30.84667	-3.24131
00:38	29.45	28.40704	-3.54146	29.45	29.05528	-1.34031	31.472	30.90459	-1.8029
01:08	29.45	28.35184	-3.7289	29.35	28.77513	-1.95867	31.37	30.78888	-1.85247
01:38	29.35	28.24167	-3.77625	29.35	28.4788	-2.96831	31.268	30.59143	-2.16378
02:08	29.25	28.13983	-3.79545	29.35	28.29152	-3.60641	31.268	30.43425	-2.66646
02:38	29.05	28.05655	-3.41979	29.35	28.062	-4.38842	30.457	30.29329	-0.53751
03:08	28.95	27.99828	-3.28746	29.35	27.94861	-4.77475	30.054	30.19205	0.45934
03:38	28.95	27.9491	-3.45734	29.25	27.88077	-4.68113	30.457	30.10105	-1.1687
04:08	28.85	27.91619	-3.23678	29.25	27.90732	-4.59036	30.963	29.05279	-6.16933
04:38	28.75	27.90768	-2.92981	29.25	27.85206	-4.77928	30.963	28.91666	-6.60898
05:08	28.85	27.91097	-3.25487	29.25	27.83804	-4.82721	31.064	29.05318	-6.47315
05:38	28.75	27.92231	-2.87892	29.15	27.8286	-4.5331	30.963	29.28146	-5.4308
06:08	28.46	28.06806	-1.37716	29.15	27.79686	-4.64199	30.963	30.79084	-0.55602
06:38	28.66	28.34976	-1.08248	29.15	28.10435	-3.58714	31.166	31.63985	1.520407
07:08	28.56	28.59078	0.107773	29.05	28.6794	-1.27573	31.472	32.39644	2.937341
07:38	28.75	28.92077	0.593983	29.15	29.02623	-0.4246	31.88	32.98713	3.472804
08:08	28.95	29.37852	1.480207	29.15	29.19763	0.163396	32.394	34.30648	5.903809
08:38	29.15	29.4679	1.090566	29.15	29.37089	0.75777	32.6	34.46177	5.710951
09:08	29.05	29.64287	2.040861	29.25	29.60002	1.19665	32.807	34.57147	5.378334
09:38	29.15	29.69343	1.864254	29.35	29.87382	1.784736	32.911	34.63737	5.245571
10:08	29.25	29.70398	1.552068	29.35	30.18196	2.834617	32.911	34.58513	5.08684
10:38	29.45	29.71157	0.888183	29.45	30.38428	3.172428	33.014	34.52242	4.569031
11:08	29.65	29.75211	0.344384	29.65	30.74602	3.696526	32.6	34.58613	6.092423
11:38	29.85	29.84979	-0.0007	29.75	31.24654	5.030387	32.497	34.77888	7.021817
12:08	29.95	29.897	-0.17696	29.85	31.23948	4.654874	32.394	34.90302	7.745323
12:38	30.15	29.90184	-0.82308	29.95	31.11244	3.881269	32.291	35.0526	8.552228
13:08	30.26	29.88188	-1.24957	30.56	30.94349	1.254876	32.086	35.29752	10.0091
13:38	30.46	29.85371	-1.99045	30.56	30.76478	0.670092	32.086	35.52518	10.71863
14:08	30.56	29.82105	-2.41803	30.36	30.59672	0.77971	31.983	35.71348	11.66395
14:38	30.66	29.78112	-2.86654	30.36	30.4242	0.211462	32.188	35.80984	11.25214
15:08	30.76	29.73348	-3.33719	30.36	30.23347	-0.41677	32.394	35.8716	10.73532
15:38	30.86	29.68581	-3.80489	30.46	30.05173	-1.34035	32.394	35.82854	10.6024
16:08	30.86	29.65536	-3.90356	30.36	30.00152	-1.18076	32.704	34.61544	5.844667
16:38	30.86	29.62686	-3.99592	30.36	29.9722	-1.27734	33.014	34.36289	4.085812
17:08	30.86	30.04198	-2.65075	30.36	30.21616	-0.47378	33.014	33.74639	2.218422
17:38	30.76	30.18291	-1.87611	30.26	30.12171	-0.45701	33.014	33.20536	0.579633
18:08	30.76	29.99372	-2.49116	30.05	30.81038	2.530383	32.911	31.73466	-3.57431
18:38	30.66	29.8682	-2.58252	29.85	31.344	5.005025	33.014	31.434	-4.78585
19:08	30.46	29.76069	-2.29583	29.75	31.1354	4.656807	33.118	31.02699	-6.31382
19:38	30.36	29.6427	-2.36265	29.75	31.03085	4.305378	32.911	30.7443	-6.58351
20:08	30.15	29.58747	-1.86577	29.65	31.0504	4.723103	32.6	30.65497	-5.96635
20:38	30.05	29.55958	-1.63201	29.45	31.03656	5.387301	32.394	30.60239	-5.53068
21:08	29.95	29.40208	-1.82945	29.35	30.99251	5.596286	32.394	30.52273	-5.77659
21:38	29.85	29.27533	-1.92519	29.45	30.95324	5.10438	32.291	30.44197	-5.72615
22:08	29.85	28.95364	-3.00288	29.45	30.26028	2.751375	32.291	30.3841	-5.90536
22:38	29.85	28.74129	-3.71427	29.45	29.81869	1.251919	32.188	30.33265	-5.7641
23:08	29.95	28.6794	-4.2424	29.35	29.56019	0.71615	32.188	31.01561	-3.64232
23:38	29.85	28.64666	-4.03129	29.35	29.16807	-0.61986	32.086	31.09602	-3.0854

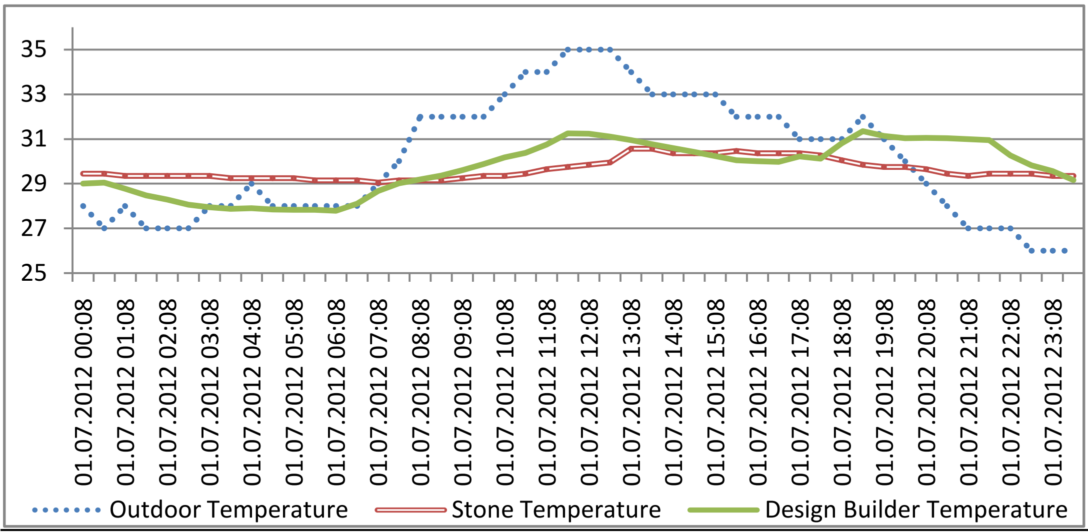

Figure 10 Stone House: Actual temperature with outdoor and DesignBuilder simulation

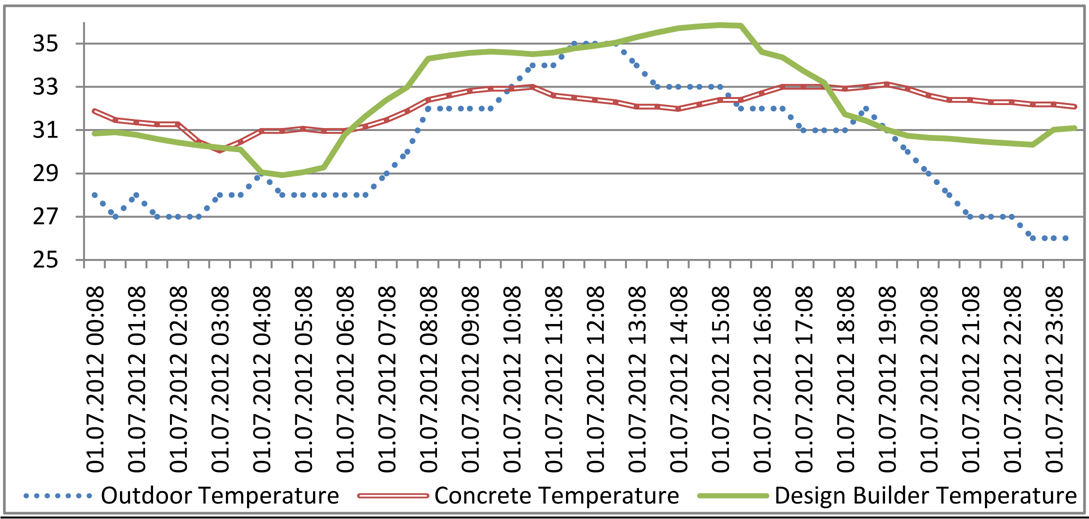

Figure 11 Concrete House: Actual temperature with outdoor and DesignBuilder simulation

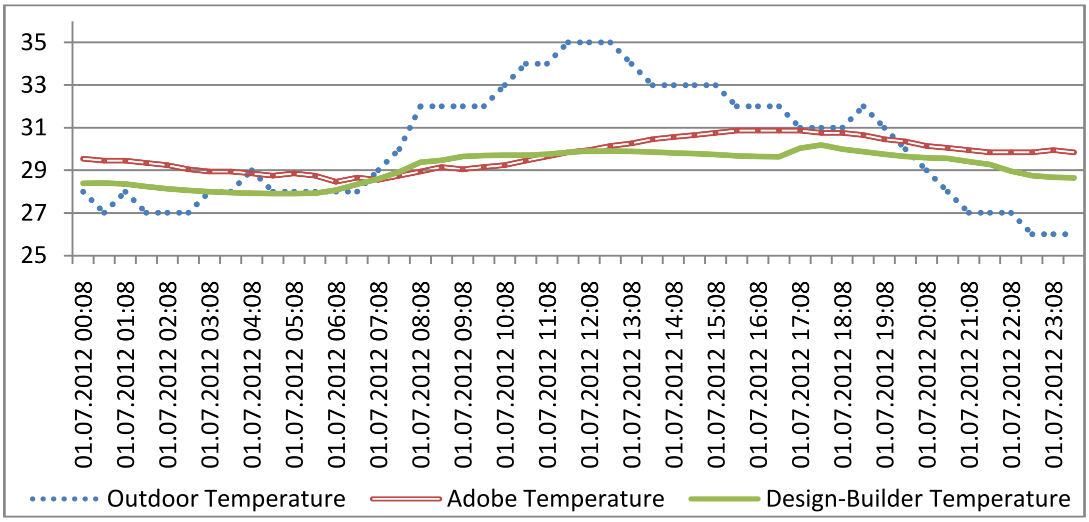

Figure 12 Adobe House: Actual temperature with outdoor and DesignBuilder simulatio

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