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Outdoor thermal and visual perception of natural cool materials for roof and urban paving

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Abstract

Given the acknowledged thermal performance of natural light color gravels applied as cool roof and cool urban paving, this work is aimed at investigating if such behavior is perceivable by pedestrians, who are questioned in this paper about their visual and thermal comfort perception. In fact, there are still related aspects to analyze, in order to optimize their application and provide a comfortable space for users, both on the thermal and the visual point of view. Therefore, the question that this work wants to answer is: given their intrinsic characteristics, do these materials create a sensitive thermally and visually more comfortable environment for pedestrians? In order to address this uninvestigated issue, users' judgment about visual and thermal comfort of these surfaces is considered, also by comparing them with grassland and asphalt. Also, the statistical correspondence between physical properties of such materials and possible correspondence with respect to human perception with varying weather conditions is analyzed. Given the relatively high reflectance of these materials, it appears particularly important to evaluate these aspects, to consciously apply them as urban paving or roof covering by optimizing their natural passive cooling potential. In this preliminary study, users' response to these surfaces is evaluated by mean of field surveys, both on the thermal and the visual evaluation, and contemporary in-field measurements of surface parameters. Also, human perception with respect to these high-reflectance surfaces' is compared with the one related to grassland and asphalt, with varying weather conditions. Then, a statistical analysis is performed to investigate the differences among different gravels, grassland and asphalt, based on surveys' results. The results show how pedestrians, questioned during summer days, prefer grassland, while asphalt is the less favorite surface both visually and thermally; there is a small difference between gravels' types evaluation, while weather variability affect the preferences.

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Keywords: outdoor thermal comfort; outdoor visual comfort; cool materials; cool natural gravels; energy efficiency; passive system; urban heat island.

1. Introduction

Nowadays, buildings' energy efficiency is a fundamental focus for researchers, given the impact that built environment has on the total final energy consumption [1]. Thus, by studying and optimizing this field, huge amount of energy could be saved. The need for energy efficiency and savings is highlighted also by the EU Research and Innovation Program, Horizon 2020[1], whose important objective for 2020, and consequently for 2050, is to consistently reduce greenhouse gas emissions up to 80-95%. In this scenario, several energy savings strategies are considered and implemented, in order to reach the ideal solution of a Zero (or Near to Zero) Energy Building, which is a building whose final energy consumption is zero, considering a balance of the gains and losses.

In particular, passive solutions are regarded as optimal strategies to reach building's energy efficiency: this is due to the fact that these solutions permit to reduce energy consumption and reach indoor comfort levels without any power consumption, or in any case minimizing energy use. The first passive strategy to adopt is a conscious design of the building [3] and the implementation of effective building envelope components [4], depending on local climate and conditions. Campanico et al. [5] and Wang et al.[6] in their work assess the decrease of cooling demand due to natural ventilation, whose advantage is to reduce energy consumption while improving indoor air quality. Other passive solutions comprehend the implementation of roof strategies, i.e., roof ponds [7], green roofs [8] and cool roofs.

Cool roofs system consists of flat roofs – considering different occupancy and building destination - covered by high reflective and high emissivity materials, referred to as cool materials [9]. These materials are able to maintain their surface cooler than a roof covered with low reflective and emissivity materials. This cooler surface results in a smaller solar heating load in the indoor area and, consequently, in a decreased cooling energy demand during summer: in their work, Kolokotsa et al. [10] considered a cool roof application on a laboratory building in Crete, Greece, and by performing a numerical and experimental analysis demonstrated how this technology permitted to reduce energy consumption up to 19.8%. Also, besides cooling demand decrease during summer, heating demand penalties during winter are almost negligible [11], even in cold climate conditions.

Other studies analyze natural materials for cool applications, whose optic and thermal characteristics appear to be particularly suitable for this purpose. White marble panels for building envelope applications are taken into account in Rosso and colleagues research [12]: given the intrinsic high reflectance and emissivity of this materials, they showed by mean of in lab measurements and dynamic simulation how the envelope is able to decrease energy requirement for cooling up to 20% - with respect to traditional cement based tiles - given the optical characteristics of the natural stone. In their work [13], Pisello et al. consider cool roof application of natural stone gravels with different grain sizes, performing in-field albedo and in lab optic and thermal characteristics measurements. These materials are low-cost, locally available as waste of production in many countries and regions, and durable (comparing them to membranes or other common roof systems): stone gravels are sustainable not only for the application as energy saving strategy, but also for their physical and economical characteristics. They compared five gravels' optic characteristics with varying grain size, assessing albedo decrease with grain dimension. Cool materials are also analyzed for their potential in reducing Urban Heat Island (UHI) phenomena, when applied as urban paving [14]. As above mentioned, cool roof system is beneficial for indoor thermal conditions, while cool paving are beneficial for urban areas' comfort.

However, while high reflectance and albedo values are optimal for energy efficiency, on the other hand they could lead to outdoor visual and thermal discomfort for pedestrians utilizing those spaces. Thus, the aim of this research is to evaluate if these materials' surfaces are visually and thermally comfortable, given their high reflectance, by mean of field surveys. The authors intend to investigate human perception of this smart solution, also by cross-checking surveys' results, carried on during different weather conditions, with in field measured weather data. Surveys have been conducted both on the thermal users' perception and on the visual perception of outdoor surfaces. Moreover, gravels' surfaces have been compared with traditional surfaces (i.e., asphalt and grass). Finally, a statistical analysis has been performed to compare perception of different surfaces and weather conditions.

2. Materials and methods

2.1. Research Procedure

2.1.1. Gravels' Field Characterization

Five gravels' fields have been considered (Table 1) [13], each one measuring 4m × 4m and each one characterized by a different gravel type (Figure 1.(a)). Four gravels are composed of natural stone with high reflectance, locally available in Central Italy, each one with different homogeneous grain size. One gravel is a common mixed natural gravel, showing lower solar reflectance and albedo. All the fields have been disposed on the roof of Perugia University Engineering Faculty building. The gravels have been in lab characterized regarding Solar Reflectance (300-2500 nm range is considered) with Shimadzu spectrophotometer (Shimadzu, SolidSpec 3700 spectrophotometer, Japan, Kyoto [15]) according to ASTM E903-12 [16]. For albedo in filed measurements, an albedometer has been employed (Figure 1. (a)), following the directions of ASTM E1918 [17].

Table 1. Gravels composition and .characterization

GRAVEL TYPE	NAME	GRAIN SIZE [mm]	SOLAR REFLECTANCE [%]	ALBEDO [%]
local natural stone with high reflectance	G1	8–22.4	38	36
	G2	4–12.5	50	39
	G3	2–5.6	45	40
	G4	0–4	62	44
common mixed natural gravel	G5	4–12.5	27	29

Figure 1. (a) Gravels field overview with albedometer; (b) meteorological sensors.

2.1.2. Weather Conditions monitoring

A continuous monitoring has been performed as in [18], (Figure 1(b)). Sensors for meteorological monitoring (Table 2) took measurements every 20 s, while wind velocity has been recorded every 5 s. Thus it was possible to consider the exact values of the precise time (averaged every 10 m) when the surveys were carried out.

Table 2. Monitoring set up sensors and measured parameters.

UTILIZED MONITORING SENSORS	MEASURED METEOROLOGICAL PARAMETERS	MEASUREMENT FEATURES
Air speed sensor	Wind velocity [m/s]	Accuracy: 0.1 m/s sensitivity: 0.4 m/s
Thermohygrometer sensor	Dry bulb temperature, Tout [◦C]	Accuracy: 0.1 ◦C (0 ◦C)
	Air relative umidity [%]	Accuracy: 1.5% (5÷95%, 23 ◦C)
Direct radiometer (with sunshine duration sensor)	Sunshine duration (referred to acertain threshold) [0–1]	
	Direct radiation from the sun [W/m2]	Accuracy: 5% + 5 W/m2
Thermopile global radiation sensor (piranometer upward oriented)	Global solar irradiance [W/m2]	Spectral range: 305÷2800 nm
		Uncertainty: 10% daily

2.1.3. Field Surveys

The surveys have been performed during typical summer days, 9th of July and 18th of July, during the hottest hours of the day, i.e., from 12.00 am to 1.30 pm, in Perugia, Central Italy. The 9th of July the interviewees have been 25, while the 18th of July they have been 31, for a total of 66 interviewees. These interviews are transversal studies, meaning that each person participated only once to the survey. After some minutes of adaptation, they were asked to fill the visual comfort survey first, and then the thermal comfort part, in order to allow a more complete thermal adaptation to the environment. The survey has been conducted in Italian language, to be more exactly and easily understandable to the interviewees: the language has been used accordingly to the specifications given by UNI ISO 10551-1995 [19][18].

2.1.3.1. Thermal Comfort

Many works have been published about thermal outdoor comfort surveys; however, like Johansson and colleagues explain in their work [20], even if there is a huge database of studies of subjective outdoor thermal comfort, since these studies have been conducted worldwide in different climates and cultures, and given the lack of standardization, it is difficult to compare results. In this research, UNI ISO 10551-1995 [19][18] was applied for surveys' design, in order to provide objective and standardized results to pair with the measured meteorological conditions.

2.1.3.2. Visual Comfort

Differently than for thermal comfort surveys, even if many works focused on indoor visual comfort, to the best of authors' knowledge, there are not studies about outdoor visual comfort related to materials. Thus, also for consistency with thermal comfort survey, UNI ISO 10551-1995 [19] has been applied again for designing visual comfort survey, adapting it to the visual field (i.e., thermal acceptability corresponds to visual acceptability).

2.1.4. Statistical analysis

Data have been statistically analyzed with STATA statistical software [21], to check the significance of the comparisons.

3. Results And Discussions

3.1. Covered sky- windy day: monitoring and survey

Table 3. Monitored meteorological data, 9th of July – averaged values.

July 9th	Air relative humidity [%] - average	Air Temperature [°C] - average	Global solar irradiance (W/m2) - average	Wind velocity (m/s) - average	Sunshine Duration [%]
Ave. values 12.00-1.30	0.28	23.3	659.8	3.9	4

The 9th of July has been a very variable, cloudy and windy day, atypical for that period of summer (Table 3). Regarding thermal comfort, the statistical analysis highlighted how, on the preference scale, gravels and grass are perceived as significantly more comfortable than asphalt surface (Figure 2.(a)). Considering only gravels, users' perception is not statistically different depending on gravels' size. They are all evaluated as acceptable and tolerable, like grass surface, while asphalt is considered almost thermally unacceptable and intolerable. Visually, users expressed their preference for a less light environment for all the gravels, while regarding asphalt and grass they would have preferred a lighter surface (Figure 2. (b)). However, all the considered gravels generally resulted acceptable and tolerable. Grass is considered the most comfortable surface, while asphalt, according to results, even if users declared it as visually comfortable, is intolerable to the view. To allow a general comparison among the considered surfaces, the overall sum of each survey question score has been assessed and displayed in (Figure 3. (a), (b)), both for thermal and visual perception.

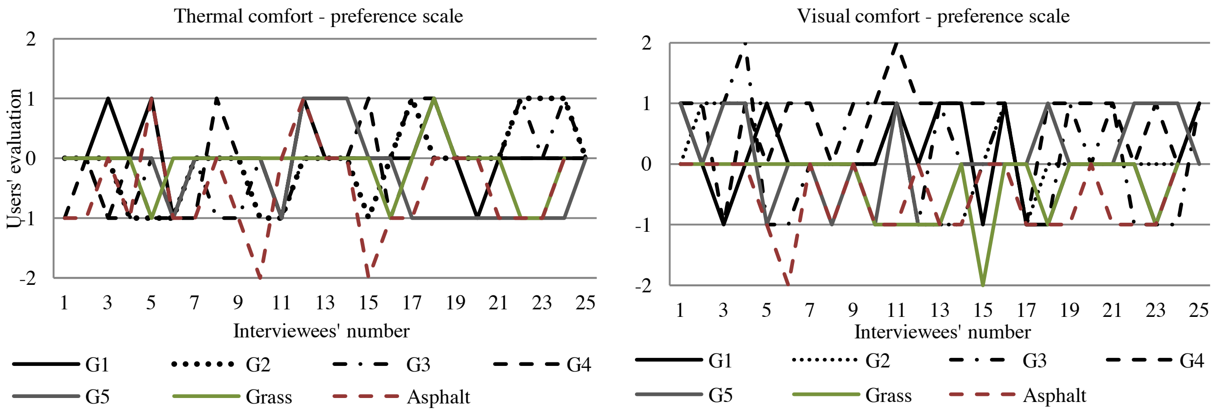

Figure 2. Preference scale (a) Thermal comfort: -2 they would prefer it cooler, 0 neutral, 2 warmer; (b) visual comfort: -2 they would prefer it lighter, 0 neutral, 2 less light.

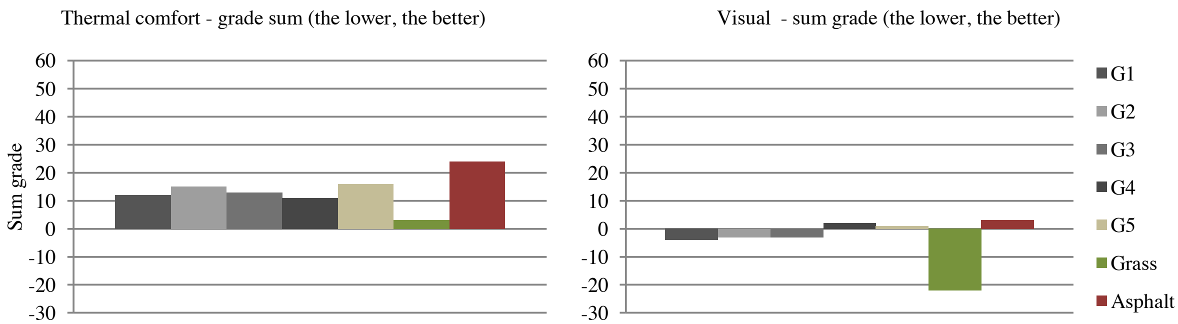

Figure 3. Comparative value: sum grade (a) for thermal comfort and (b) for visual comfort.

3.2. Sunny day: monitoring and survey

Table 4. Monitored meteorological data, 18th of July – averaged values.

July 18th	Air relative humidity [%] - average	Air Temperature [°C] - average	Global solar irradiance (W/m2) - average	Wind velocity (m/s) - average	Sunshine Duration [%]
Ave. values 12.00-1.30	0.29	29.6	1071.2	3.1	10

Differently from the first day of in field survey, the 18th of July has been a typical summer day (Table 4)**.** The statistical comparisons give more significant results than for 9th of July, confirming that in more extreme conditions many differences are perceived. Concerning thermal comfort, users state their preference for grass and gravels (Figure 4); among gravels, no significant differences are perceived (Figure 5 (a)). Asphalt, again, is the least preferred (Figure 4 (b)). However, visually, G5, G1, G2, are preferred to the other gravels, accordingly with their reflectance values, which are lower than for G3 and G4. G4, the gravel characterized by smaller grains and higher reflectance, is perceived as visually unacceptable and intolerable by a consistent part of the interviewees. Asphalt and grass are regarded as visually preferred surfaces in terms of comfort and light quantity; however, again asphalt is evaluated as intolerable and slightly acceptable to the view. The comparative assessment of a global grade perception (Figure 5, (a), (b)) confirms these results.

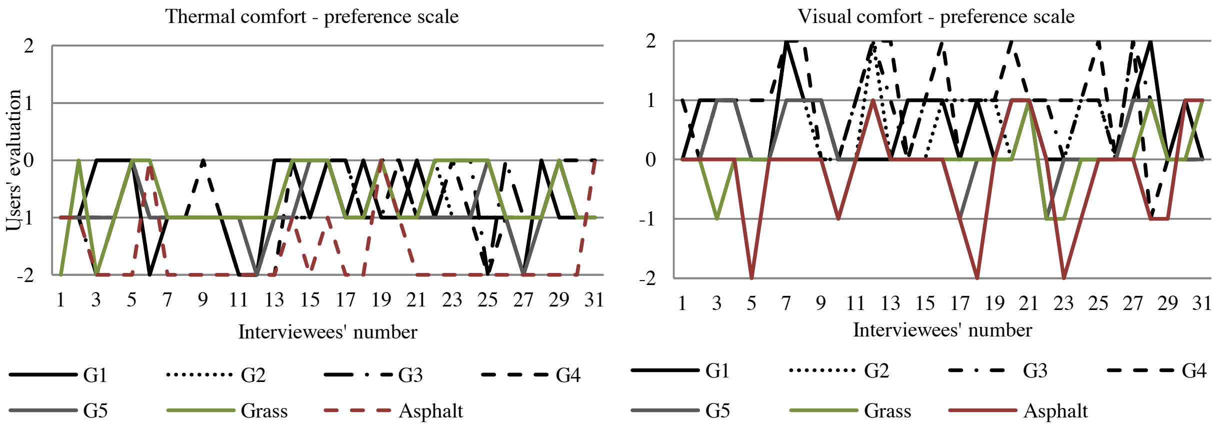

Figure 4. Preference scale:(a) thermal comfort: -2 they would prefer it cooler, 0 neutral, 2 warmer; (b) visual comfort: -2 they would prefer it lighter, 0 neutral, 2 less light.

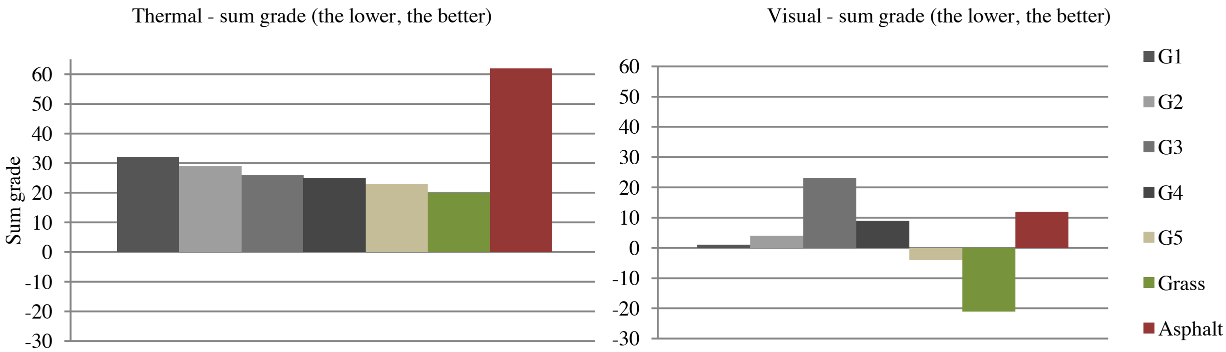

Figure 5. Comparative value: sum grade (a) for thermal comfort and for (b) visual comfort.

4. Conclusions

This work presented an experimental study about outdoor visual and thermal perception of natural gravels for cool roof and paving. Given the high reflectance and thermal emissivity of the selected stones for passive cooling purpose, the objective was to investigate how much comfortable these surfaces are, compared to more common ones, i.e., grass and asphalt. Moreover, since gravels vary their field albedo with varying grain size, a comparative analysis between differently grained gravels' perception is assessed. Also, weather variability is considered during the analysis, to cross-check different surfaces perception with varying weather conditions. Thus, four gravels' field with high reflectance and decreasing grain size, G1, G2, G3, G4 and a field composed by common mixed gravels, G5, alongside with grassland and asphalt, are evaluated by mean of field surveys, conducted in two summer days with different meteorological conditions.

The first day was cloudy: this situation could be assimilated to an urban area situation, where surrounding buildings shade the paving, since there was a few beam solar radiation. The second day of investigation was sunny and more summer-typical. The results demonstrate that during cloudy and cooler days, gravels and grass are visually preferred to other surfaces, while thermally grass is the most preferred one and asphalt the least preferred one. Generally, there is not statistically significant difference in the perception of gravels depending on grain size. On the contrary, during typical sunny days, gravels are consistently preferred referring to thermal perception: 77% of the interviewees state G all tolerable and acceptable, while this percentage grows up to 94% for grassland; on the contrary, referring to asphalt 77% of interviewees perceive it as thermally intolerable. Nevertheless, gravels are considered slightly visually unacceptable and slightly tolerable, due to glare sensation. In particular, G5, the one with lower reflectance, is the preferred one, with 85% interviewees considering it acceptable and 83% tolerable; then, in order of preference, G1, G2-G3 and G4, which, with the highest reflectance, is the least preferred. In this case, grass is perceived as the most visually comfortable surface: 95% consider it acceptable and tolerable.

The results of this research could be useful to correctly choose the paving materials for pedestrian areas' design: in fact, cool materials, as the gravels here analyzed, could help mitigating Urban Heat island effect in dense areas, if correctly employed. However, depending on the location, they have to be carefully applied. If the gravel surface is walkable by pedestrians and the location is very sunny, attention should be paid to avoid unpleasant visual perception for users. However, if the aim of the high reflective gravel field is to be applied as natural cool roof, then the application is safe since it does not affect any pedestrians' perception. Also, these natural local materials showed to be an optimal solution for urban paving, where the shades of surroundings decrease glare effects, while UHI reduction and indoor comfort increase could be reached.

5. Future Developments

Other research should be carried out to extend surveys to more interviewees and days, both during summer and winter. Different locations with different climate should be analyzed and compared. More surfaces could be analyzed.

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Authors' contributions

Federica Rosso is a Ph.D. whose main research interest is the analysis of natural stone solutions for energy savings; she is the main author of the work, and contributed to the experimental campaign and paper writing. Anna Laura Pisello is an assistant professor leading the work development and the experimental activities. Gloria Pignatta,

Veronica Lucia Castaldo and Cristina Piselli are Ph.D. students contributing to the field survey activity. Franco Cotana and Marco Ferrero are the professors supervising the energy and the architectural analyses.

References

[1] L.P. Lombard, J. Ortiz, C. Pout, A review on buildings energy consumption information, Energy and Buildings 2008, 40, 394-398.
[2] Horizon 2020, The UE Framework Programme for research and Innovation, available online at **http://ec.europa.eu/programmes/horizon2020/**, accessed on 30th January 2015.
[3] R. Pacheco, J. Ordonez, G. Martinez, Energy efficient design of building: A review, Renewable and Sustainable Energy Reviews 16 (2012) 3559–3573.
[4] Suresh B. Sadineni, Srikanth Madala, Robert F. Boehm, Passive building energy savings: A review of building envelope components, Renewable and Sustainable Energy Reviews 15 (2011) 3617–3631.
[5] H. Campaniço, P. Hollmuller, P. M.M. Soares, Assessing energy savings in cooling demand of buildings using passive cooling systems based on ventilation, Applied Energy 134 (2014) 426–438.
[6] Y. Wang, F.Zhao, J. Kuckelkorn, D. Liu, J. Liu, J.Zhang, Classroom energy efficiency and air environment with displacement natural ventilation in a passive public school building, Energy and Buildings 70 (2014) 258–270.
[7] A. Spanaki, T. Tsoutsos, D. Kolokotsa, On the selection and design of the proper roof pond variant for passive cooling purposes, Renewable and Sustainable Energy Reviews 15 (2011) 3523–3533.
[8] I. Jaffal, S. Ouldboukhitine, R. Belarbi, A comprehensive study of the impact of green roofs on building energy performance, Renewable Energy 43 (2012) 157-164.
[9] A.L. Pisello, F. Rosso, Natural Materials for Thermal Insulation and Passive Cooling Application, Key Engineering Materials, Trans Tech Publications 666 (2015) 1-16.
[10] D. Kolokotsa, C. Diakaki, S. Papantoniou, A. Vlissidis, Numerical and experimental analysis of cool roofs application on a laboratory building in Iraklion, Crete, Greece, Energy and Buildings 55 (2012) 85–93.
[11] A.L. Pisello, F. Cotana, The thermal effect of an innovative cool roof on residential buildings in Italy: Results from two years of continuous monitoring. Energy and Buildings 2014, 69, 154-164.
[12] F. Rosso, A.L. Pisello, F. Cotana, M. Ferrero, Integrated Thermal-Energy Analysis of Innovative Translucent White Marble for Building Envelope Application, Sustainability 6 (2014) 5439-5462.
[13] A.L. Pisello, G. Pignatta, V. Castaldo, F. Cotana, Experimental Analysis of Natural Gravel Covering as Cool Roofing and Cool Pavement, Sustainability 2014, 6, 4706-4722.
[14] M. Santamouris, Using cool pavements as a mitigation strategy to fight urban heat island—A review of the actual developments, Renewable and Sustainable Energy Reviews 26 (2013) 224–240.
[15] Shimadzu Excellence in Science. Available online: http://www.shimadzu.com/an/spectro/uv/solidspec/solid.html (accessed on 29 January 2015).
[16] American Society for Testing Materials. ASTM E 903-96 Standard Test Method for Solar Absorptance, Reflectance, and Transmittance of Materials Using Integrating Spheres; American Society for Testing Materials: West Conshohocken, PA, USA, 1996.
[17] American Society for Testing Materials . ASTM E 1918 Standard Test Method for Measuring Solar Reflectance of Horizontal and Low-Sloped Surfaces in the Field; American Society for Testing Materials: West Conshohocken, PA, USA, 1996.
[18] A. L. Pisello, F. Cotana, A. Nicolini, C. Buratti, Effect of dynamic characteristics of building envelope on thermal-energy performance in winter conditions: In field experiment, Energy and Buildings 80 (2014) 218–230.
[19] International Organization for Standardization. ISO 10551 1995 Ergonomics of the thermal environment - Assessment of the influence of the thermal environment using subjective judgement scales; International Organization for Standardization: Geneva, Switzerland, 1947.
[20] E. Johansson, S. Thorsson, R. Emmanuel, E. Krüger, Instruments and methods in outdoor thermal comfort studies – The need for standardization, Urban Climate 10 (2014) 346–366.
[21] STATA Statistical Software, vailable online at http://www.stata.com/, accessed on 29th January 2015.