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ARTICLE

A Comparative Study of the Thermal Performance of Plastic Bottle Wall against Traditional Composite Brick Wall Typologies

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ABSTRACT

According to the container recycling institute, nearly a million plastic beverage bottles are sold every minute around the world. Plastic bottles are considered as an urban junk, however, it has shape characteristics which make them usable in construction in lieu of conventional bricks. This research promotes the use of recycled plastic bottles as eco-bricks by substituting it with the typical construction bricks. It evaluates the thermal performance of sand filled plastic bottle-walls in a comparative analysis with traditional composite brick walls. The thermal performance of the plastic bottle walls was evaluated through COMSOL® Multi-physics and the results are noted.

1. Introduction

According to Plastic Europe [1], plastic is a material that is essential is several industries. Plastic consumption has increased from 200 million tons/year in 2002 to 322 million tons in 2015 and is expected to reach 485 million tons in 2030 [1]. Plastic is a harmful material for the environment as it is considered non-biodegradable waste that causes levels of pollution as a result of its long-lasting existence to reach insolubility which is almost 300 years. Carbon monoxide and black smoke are primary causes of toxic pollution as a result of open burning of plastic, therefore, it is considered one of the primary environmental pollutants on the plant [2]. As shown in Figure (1), in the USA, the largest plastic disposing technique since 1960 was the landfilling technique followed with the combustion with energy recovery and then a small portion of plastic compared to the proportion of produced ones has been recycled. Due to the form and flexible nature of plastic bottles, an accumulation of it could require high storage areas and accordingly it assumes large spaces of sanitary landfill. Some plastic wastes were dumped into the shoreline or ocean up to 12.7 million metric tons in 2010 [3-4] and consequently affected the marine organisms [5].

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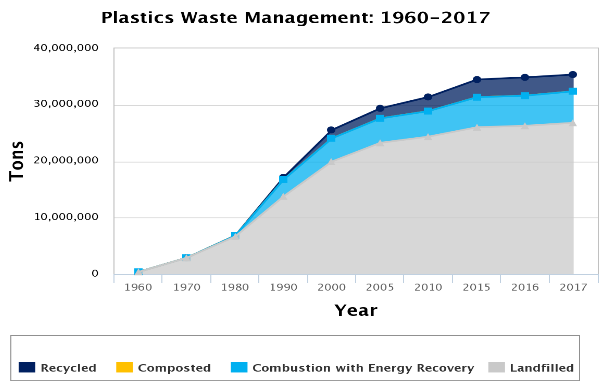

Figure 1. Different plastic waste management techniques in USA from 1960-2017 [12]

Accordingly, the reduction of plastic wastes, or plastic recycling, is the only option to reduce the environmental impacts caused by the prolonged impact of plastic waste. Plastic wastes were utilized through recycling and energy recovery (around 48-69%) in 2006 to 2014 [1]. In developing countries, the industry and rate of waste recycling is relatively low. Much of the problem lies in the improper waste management, collection practices and methods of plastic waste separation. In addition, much of the available techniques contribute to additional wastewater and air pollution and a substantial increase in the associated emissions from burning and transport. Hence, the best solution is reusing for which no additional addition to that, recycling needs additional energy to treat the materials for producing something usable and also, the process of recycling energy is required and does not contribute to pollution. Using filled plastic bottle in construction is one of the beneficial forms of plastic reusing. Plastic especially PET (polyethylene terephthalate) bottles, is a very difficult and costly process [6-9]. Moreover, the cost of construction using filled plastic bottles is lower than that of using conventional materials like brick. In addition, using local earth materials like local unprocessed sand ensures better thermal performance. Hence, the idea of using plastic wastes as a building material originated. The first bottle house was built using 10000 glass beer bottles by Wiliam F. peck in 1902 in Tonopha, Navada [10]. Afterwards, the newest building concepts have been using plastic bottles instead of glass in house construction. This idea of using plastic bottles in construction later grew because of the cost-efficient construction method especially in third-world countries, and the variety of solutions it provides utilizing the indecomposable plastic bottles. The first plastic bottles house in Africa was constructed in the village of Yelwa in Nigeria by Andreas Forese as shown in Figure 2. Forese used the plastic bottles instead of bricks, bound the bottles together with string and at the end applied the plaster [11]. Despite that building walls with plastic bottles instead of typical construction materials have been widely used in the past with success, both the industry and research focused on the investigation of the structural and thermal response of the plastic bottles were not taken seriously until couple of years ago.

Figure 2. The first two-bedroom bungalow made of entirely sand filled plastic bottles

A research study in 2015 focused on examining the thermal and structural response of walls using a comparative study of dry sand, saturated sand and empty plastic bottles. Brick work made of PET pieces were subjected to unconfined compressive stacking employing a compression machine of 3000 kN capacity and of an accuracy of 0.10 kN and after that the stacking was connected on the square in a way of the bottles laying evenly and subjected to a uniform compression mode, which simulates the way they are utilized in different wall typologies. In addition, the thermal examination was done by reenacting the simulated models of the three brick work squares on ECOTECT computer program. The results show that the impact of the infill fabric on the bulk unit weight and the compressive quality of the plastic bottle stone work pieces appeared slight effect of the utilized infill fabric on the quality. The gross strength of plastic bottles (670 kN/m^2) is much less than the traditional blocks (3670 kN/m^2), but the resulting data showed that the blocks of air-filled plastic bottles can still be used as suitable construction units for partition walls or as load-bearing walls for roof slab types. Thermally, plastic air-filled bottles show more improved thermal insulation characteristics than the traditional masonry construction, which could work as a thermal insulation material [13].

A similar study in Malaysia was published in which a comparison was performed between plastic bottle walls filled with brick and sand filled bottle walls. The strength of the walls filled with brick was three times stronger more than the sand filled bottle walls. However, the sand filled bottle wall system had an acceptable strength as it passed minimum permissible strength of Public Work Department (PWD) Standard Specification for Building Works (2008). Hence, the plastic bottle bricks had the capability to replace standard bricks in Malaysia's buildings in condition of thermal comfort [14]. A similar

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study focused on the thermal performance of sand filled plastic bottle walls was performed in Egypt, in which the researchers compared the traditional bricks and building with plastic bottle blocks utilizing energy simulation software on two sample rooms fitted with both materials. Onsite measurements for energy performance of the rooms were also taken. The results showed that the average temperature in brick room was higher than in the plastic bottles room. However, the relative humidity was higher in plastic bottles room [15]. Similar studies were performed in several other developing countries like Bangladesh, India and other Arabic countries. However, from the literature review, it is apparent that the thermal evaluation and its comparative performance against conventional wall typologies used in these counties is still not well investigated and was not focused on especially in developed countries which are the largest countries producing plastic wastes. The purpose of this research is to study the thermal performance of typical plastic bottles provided in the market as a municipal waste used in buildings in terms of calculating the thermal transmittance different material walls. It also intends to compare the characteristics of brick as a construction material with the bottle panels. The paper is organized as follows: Section 1 provides an introduction to the current research point and previews its importance. Section 2 describes in detail, the different wall systems we investigated. Section 3 discusses the results.

2. Materials and Methods

2.1 Typical "Conventional" Built Walls

Brick is a building material used to make walls, hard road surfaces and other elements in masonry construction. Usually, the term brick referred to a unit composed of clay, but it is now used to represent rectangular units made of clay-bearing soil, sand, and lime, or concrete materials. Brick has been used a lot in construction in the Middle East area and especially in Egypt. In our work, three walls representing the typical walls used in the Middle East area and Egypt were built and simulated on COMSOL [16] with the following specifications:

(1) Wall (T_1): 2.5 cm Plaster layer + 20 cm Brick layer + 5 cm Extruded polystyrene insulation layer2.5 cm + 1.3 Plaster Gypsum Wall Board (GWB) and Paint layer.

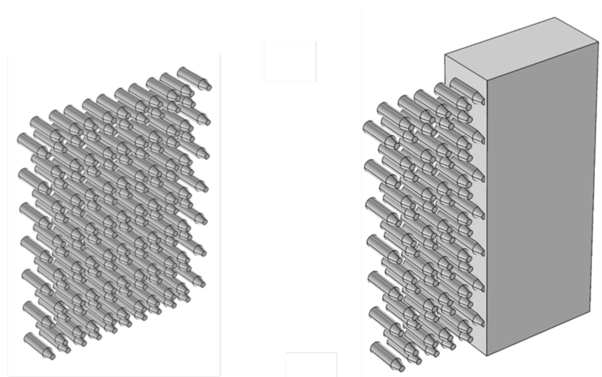
(2) Wall (T_2): 2.5 cm Plaster layer + 20 cm Brick layer + 2.5 cm Plaster layer.

(3) Wall (T_3): 2.5 cm Plaster layer + 10 cm Brick layer + 2.5 cm.

2.2 Plastic Bottles Wall

Building construction with plastic bottles is a low-cost and eco-friendly technique. The huge amount of packaging and plastic bottles is unlimited today and they comprise a large portion of the country waste which lead eventually to an increase in the greenhouse gasses worldwide. The reuse of plastic bottles is a more efficient solution than recycling. Nowadays, plastic bottles, can be utilized as a building block unit utilizing the plastic enclosure and sand fill to provide a building construction wall unit similar to bricks for small scale construction. Since walls built by bottles are lighter than the walls built by brick and block, this in turn, allow walls made of plastic bottles to be of a good response against earthquake activity. Due to the compaction of sand fill plastic bottles, the resistance of each bottle against the load is 20 times higher compared to brick. Since the plastic bottles are not fragile, they can be flexible and can tolerate sudden compressive loads without failure. This characteristic can also increase the building's bearing capacity against earthquakes. PET Bottles can be configured and joined to each other by several bonding techniques using a fish net or any equivalent tension and bracing technique. PET Bottles can be put in a vertical or horizontal configuration as illustrated in Figure 3. In our model, we used a vertical configuration as shown in Figures 4 were the bottles are plastered with mortar on each side. We performed our simulations by using two different volumes of water PET bottles; 0.75 L denoted as S-B wall and 1.5 L denoted as L-B wall and Figure 5 illustrates the dimension of both bottles.

Figure 3. Different bottle walls built in developing countries with various bottle configurations



(a) (b)

Figure 4. Illustration of a Cross-section of a plastic bottle wall: (a) Plastic Bottles (b) Plastic Bottles in Mortar layer

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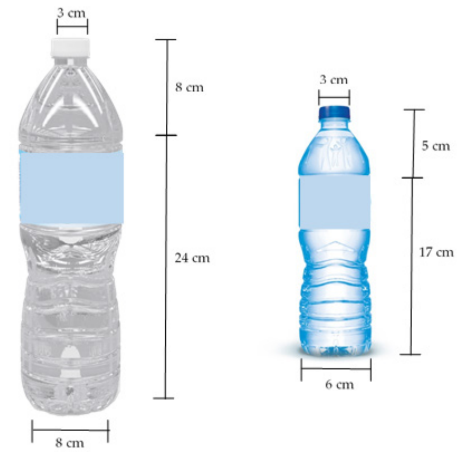

Figure 5. Dimensions of two water PET bottles used in our study

2.3 Simulation Model

COMSOL Multi-physics® is a cross-platform for finite element solver, analysis, and multi-physics simulations. It also allows conventional physics-based user interfaces and coupled systems of partial differential equations (PDEs). Heat flow and temperatures through our different walls system were measured and analyzed using COMSOL. COMSOL has been extensively used for studying several and different building related problems [17-19]; numerical results can be validated by comparison with various control systems such as thermo-flow meters, guarded hot boxes (as in the case under current analysis), and thermo-graphic techniques. The model on COMSOL is governed by three basic heat transfer equations. The heat transfers through solids, heat transfer by convection and the equation controlling the boundaries of the sample under adiabatic condition.

Heat equation of state:

$$\rho C_P \frac{\partial T}{\partial t} + \rho C_P u.\nabla T = \nabla.q + Q \tag{1}$$

Fourier's law of heat conduction:

$$q = -kA\,\Delta T \tag{2}$$

Newton's law of cooling controlling the hot and cold sides of the specimen's:

$$q = h(\,T_{ext} - T) \tag{3}$$

Adiabatic condition controlling through wall's boundaries:

$$-n.q = 0 \tag{4}$$

Where; q: Density of heat flow rate or heat flux (W/m^2), ρ: Density (Kg/m^3), C_p: Specific heat at constant pressure (J/kg K), k: Thermal conductivity [W/(m K)] and T: Temperature [K]. Figures 6 & 7 show the three typical walls & the two plastic walls system modeled in COMSOL; respectively. Table 1 illustrates the thermal and physical properties of the Brick, Concrete plaster, EPS and Gypsum wall board simulated in COMSOL. Table 2 illustrates the properties of Sand, PET and Plaster used to model the two different plastic bottle walls.

Table 1. Typical walls components specifications simulated in COMSOL

Material type	Brick	Concrete plaster	Extruded-Poly-styrene board (EPS)	Gypsum wall board
Density (kg/m^3)	2000	2300	34	574
Thermal conductivity(W/mK)	0.5	1.8	0.041	0.28
Heat capacity (J/kg.K)	900	880	1450	1100

Table 2. Plastic bottle walls components specifications simulated in COMSOL

Material type	Sand	Concrete plaster	PET
Densit (kg/m^3)	1602	2400	1380
Thermal conductivity(W/mK)	2	1.8	0.4
Heat capacity(J/kg.K)	800	880	1030

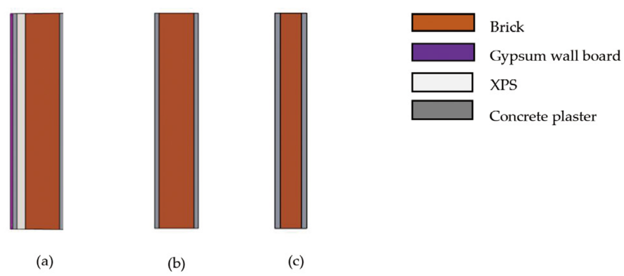

Figure 6. Illustration of typical wall systems used in Egypt residential construction in COMSOL: (a) Wall (), (b) Wall (), (c) Wall ()

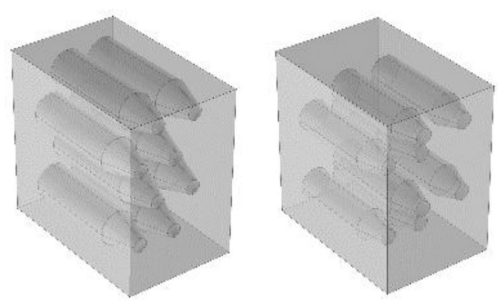

Figure 7. Illustration of two plastic bottle wall systems modeled in COMSOL: (a) Large bottle system; L-B wall, (b) Small bottle system; S-B wall

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3. Results

Protection from weather is a fundamental function of any building where mainly heat is lost and is also gained through the building envelope, i.e. walls, floors, doors, windows, ventilation and roofs. Consequently, it is important to study the thermal performance of the individual materials used in the construction of the building envelope and their resultant effect on thermal performance of the whole building. Heat flow can be measured and expressed, as "U - value" or "Thermal transmittance co - efficient". Thermal transmittance or the U-value, is the rate of transfer of heat through a structure divided by the difference in temperature across that structure. The U-value measures how effective a material is an insulator. In other words, U - values are generally used to describe the thermal performance of building elements, and also form part of the base data used to assess the energy performance of whole buildings. The U value is the reciprocal of the R-value, so it is calculated by the following equations:

$$\varnothing = A\,U.\Delta T \tag{5}$$

$$\therefore U = \frac{\varnothing}{A.\Delta T} \tag{6}$$

Where; $\varnothing$: heat flux (W), A: area of the specimen (m^2), U: thermal transmittance and : temperature different between both sides of the specimen. Another important property that influences the thermal performance of building envelopes is the "Thermal mass". Thermal mass is a property of the mass of a building which enables it to store heat, providing "inertia" against temperature fluctuations. Scientifically, thermal mass is equivalent to thermal capacitance or heat capacity, the ability of a body to store thermal energy. Therefore, concrete actually acts as a conductor of thermal energy and when it has a high thermal mass, it actually conducts thermal energy slower. The thermal energy transferred can be expressed as follows:

$$Q = mC_P\,\Delta T \tag{7}$$

Where; "Q" is the thermal energy transferred, "m" is the mass of the body, "C_p" is the isobaric specific heat capacity and ΔT is the change in temperature.

$$C_{th} = mC_P \tag{8}$$

Where; "C_{th}" is the thermal mass of the body.

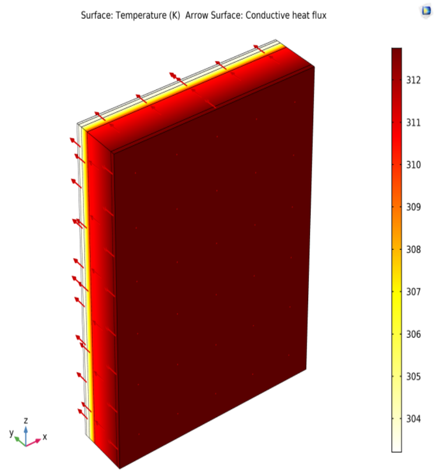

Figure 8. Illustration of temperature gradient on wall T_1 exposed to air flux of temperature 40℃ and internal air flux of temperature 30℃

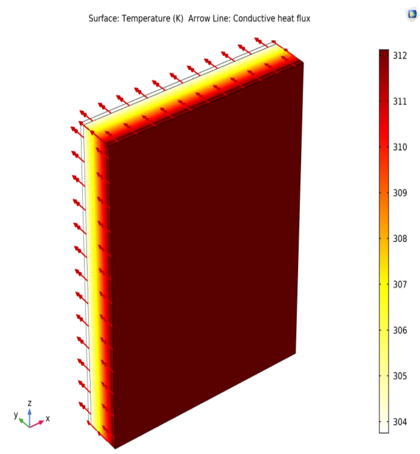

Figure 9. Illustration of temperature gradient on wall T_2 exposed to air flux of temperature 40℃ and internal air flux of temperature 30℃

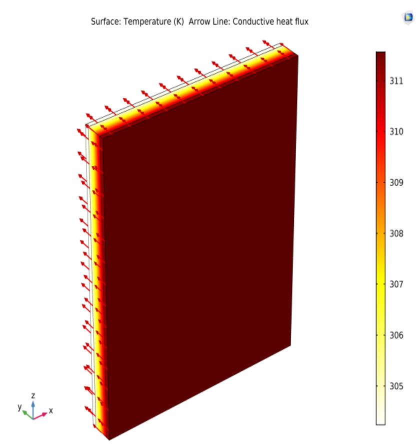

Figure 10. Illustration of temperature gradient on wall T_3 exposed to air flux of temperature 40℃ and internal air flux of temperature 30℃

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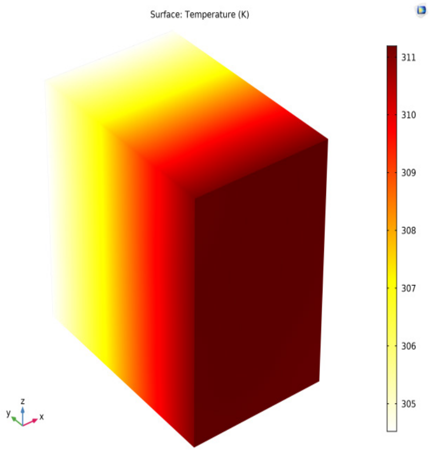


Figure 11. Illustration of temperature gradient on L-B wall exposed to air flux of temperature 40℃ and internal air flux of temperature 30℃ .

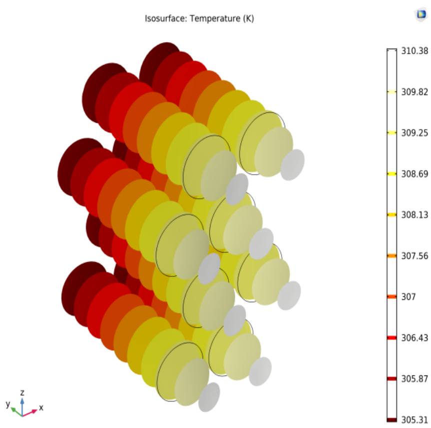


Figure 12. Illustration of temperature gradient on sand in L-B wall exposed to air flux of temperature 40℃ and internal air flux of temperature 30℃

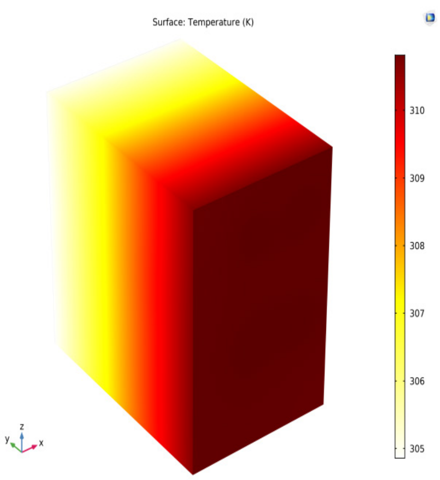


Figure 13. Illustration of temperature gradient on S-B wall exposed to air flux of temperature 40℃ and internal air flux of temperature 30℃

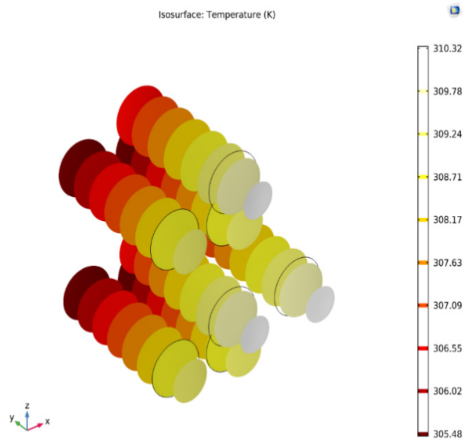
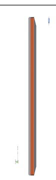
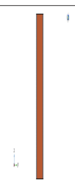
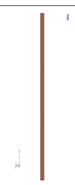
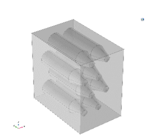
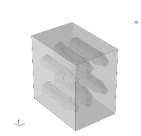


Figure 14. Illustration of temperature gradient on sand in S-B wall exposed to air flux of temperature 40℃ and internal air flux of temperature 30℃

Figures from 8 to 14 illustrates the temperature gradients in the five different wall system when exposed to hot air flux of 40 ℃ and cold air flux of 30 ℃ . Upon investigating the U-value of the five walls, results previewed that using conventional building materials with insulating layers as gypsum boards and XPS layers provide the better thermal insulation to buildings because of its high thermal mass of brick in addition to the excellent insulating characteristics of Gypsum board and XPS. However, sand contained in large plastic bottles showed a close thermal performance to Wall (T_2) and a better thermal transmittance than Wall (T_3). Small plastic bottle wall system showed the least insulation properties upon the other 4 walls. Table 3 illustrates the U-values of the five walls.

Table 3. U-value of the five wall samples

Property	Wall (T_1)	Wall (T_2)	Wall (T_3)	L-B Wall	S-B Wall
					
U-value	0.55585	1.957	3.2156	2.645	3.461

Respectively, upon increasing the outside's walls temperature from room temperature (25 °C) to (45 °C) gradually, the internal wall temperature of Wall () had the most stable temperature among the other four walls. While the large plastic wall system provided a cool internal wall temperature, but the outside wall temperature was highly affected by the external environmental temperature as shown in Figure 15.

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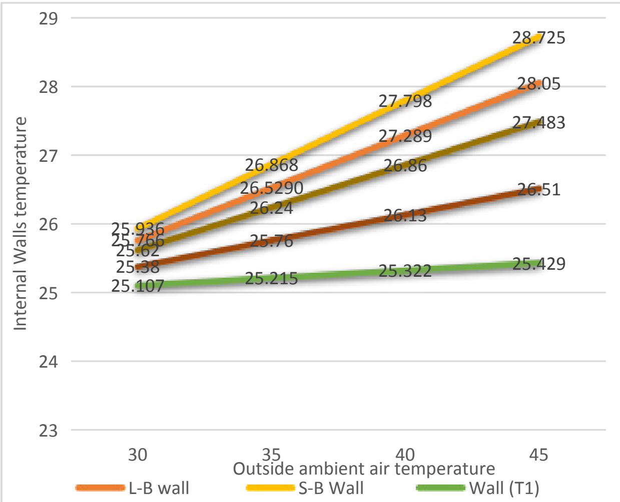

Figure 15. The change of the internal wall temperature due to the change of the outside ambient air temperature

4. Conclusion

Using Plastic bottles in construction has proved good thermal performance characteristics. Plastic bottle walls can replace brick walls as they are good insulators especially when using large bottles instead of small bottles to increase the thermal mass of the wall and still, they provide acceptable structural properties. Using large plastic bottles showed better thermal performance than brick wall type and a close performance to brick wall type The flexibility of using different glass bottle sizes and typologies, the workmanship challenges, and structural performance as a wall filler vs. a structural load bearing wall are yet issues that require further consideration. Based on the thermal performance alone, the PET bottle walls can replace traditional brick walls especially the traditional typologies formed of clay fired brick and plaster.

Acknowledgments: TBD

Conflicts of Interest: The authors declare no conflict of interest.

References

[1] Plastics Europe. Available online: http://www.plasticseurope.org/ (accessed on 10 January 2020).

[2] Junod, T.L. Gaseous Emissions and Toxic Hazards Associated with Plastics in Fire Situations-A Literature Review; NASA-TN-D-8338; NASA: Washington, DC, USA, 1976.
Jambeck, J.R., Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., Narayan, R., Law, K.L. Plastic waste inputs from land into the ocean. Science. 2015, 347, 768-771. DOI:https://doi.org/10.1126/science.1260352

[3] Alqahtani, F.K.; Ghataora, G.; Khan, M.I.; Dirar, S. Novel lightweight concrete containing manufactured plastic aggregate. Construction Building Materials. 2017, 148, 386–397.
DOI:https://doi.org/10.1016/j.conbuildmat.2017.05.011

[4] Mattsson, K., Hansson, L.A., Cedervall, T. Nano-plastics in the aquatic environment. Environmental Science: Processes & Impacts. 2015, 17, 1712-1721.
DOI:https://doi.org/10.1039/c5em00227c

[5] Lazarevic, D., Aoustin, E., Buclet, N., Brandt, N. Plastic waste management in the context of a European recycling society: comparing results and uncertainties in a life cycle perspective. Resources, Conservation and Recycling. 2010, 55(2):246-259.
DOI: https://doi.org/10.1016/j.resconrec.2010.09.014

[6] Rigamonti, L., Grosso, M., Møller, J., Sanchez, V. M., Magnani, S., Christensen, T. H. Environmental evaluation of plastic waste management scenarios. Resources, Conservation and Recycling, 2014, 85, 42-53.
DOI:https://doi.org/10.1016/j.resconrec.2013.12.012

[7] Shimao, M. Biodegradation of plastics. Current opinion in biotechnology. 2001, 12(3), 242-247.
DOI:https://doi.org/10.1016/s0958-1669(00)00206-8

[8] Urbanek, A. K., Rymowicz, W., Mirończuk, A. M. Degradation of plastics and plastic-degrading bacteria in cold marine habitats. Applied microbiology and biotechnology. 2018, 102(18):7669-7678.
DOI:https://doi.org/10.1007/s00253-018-9195-y

[9] Spaces. Available online:
http://spacesarchives.org/explore/search-the-online-collection/william-f-peck-pecks-bottle-house/ (accessed on 19 January 2020).

[10] Inhabitat. Available online:
https://inhabitat.com/africas-first-plastic-bottle-house-rises-in-nigeria/nigeria-bottle-house-1/ (accessed on 19 January 2020).

[11] United States Environmental Protection Agency (EPA). Available online: https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/plastics-material-specific-data (accessed on 21 January 2020).

[12] Mansour, A. M. H., Ali, S. A. Reusing waste plastic bottles as an alternative sustainable building material. Energy for sustainable development. 2015, 24, 79-85.
DOI:https://doi.org/10.1016/j.esd.2014.11.001

[13] Mokhtar, M., Sahat, S., Hamid, B., Kaamin, M., Kes-

ot, M. J., Law, C. W., ..., Sim, V. J. L. Application of plastic bottle as a wall structure for green house, 2015. ARPN Journal of Engineering and Applied Sciences.

[14] Abouhadid, M., Mansour, A., Shafik, R., ElRawy, O. Thermal Performance of Plastic Bottles Walls Reused in Building Construction for Waste Reduction. International Journal of Innovative Technology and Exploring Engineering (IJITEE), 2019, 9(1). ISSN: 2278-3075.

[15] COMSOL Multiphysics, Available online: https://www.comsol.com/ (accessed on February 2019).

[16] Gerlich, V., Sulovská, K., Zálešák, M. COMSOL Multiphysics validation as simulation software for heat transfer calculation in buildings: Building simulation software validation. Measurement: journal of the International Measurement Confederation. 2003, 46(6). DOI:https://doi.org/10.1016/j.measurement.2013.02.020

[17] Asdrubali, F., Pisello, A. L., D'alessandro, F., Bianchi, F., Fabiani, C., Cornicchia, M., Rotili, A. Experimental and numerical characterization of innovative cardboard based panels: Thermal and acoustic performance analysis and life cycle assessment. Building and Environment, 2016, 95, 145-159. DOI:https://doi.org/10.1016/j.buildenv.2015.09.003

[18] Baghban, M. H., Hovde, P. J., Gustavsen, A. Numerical simulation of a building envelope with high performance materials. In COMSOL conference, Paris, 2010.

[19] Vladimir, G., Michal, O., Radim, P., Martin, Z. Benchmark of COMSOL Multiphysics via in-depth floor slab test–Transient cases. Energy Procedia, 2012, 14, 744-749. DOI:https://doi.org/10.1016/j.egypro.2011.12.1005

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ARTICLE

Effects of Lizardite Addition on Technological Properties of Forsterite-monticellite Rich Ceramics Prepared from Natural Magnesite and Dolomite

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ABSTRACT

Lizardite rich peridotite has never been used to prepare ceramic specimens, especially in Morocco. For this raison, potential use of naturally abundant lizarditic material from the Rif domain, as a supply for ceramic industry, has been evaluated. The effects of lizardite addition to magnesite and dolomite mixtures on the thermomechanical properties of the calcined ceramics were also detailed. To achieve this target, natural lizardite, magnesite and dolomite samples were collected in ultrabasic Beni Bousra massif. Those raw samples were used for the synthesis of a forsterite-monticellite rich ceramics. Both raw and sintered samples were characterized by x-ray diffraction, scanning electron microscope and fourier transform infrared. The obtained results showed that both magnesite and dolomite were mainly composed of MgCO3 and CaCO3. In contrast, lizardite sample showed high amounts of SiO2, MgO and Fe2O3. An increased amount of lizardite in the initial mixtures enhanced mechanical and dimensional properties of the prepared ceramic specimens, and subsequently, the production of ceramics with the required technological properties. Thus, the preparation of Moroccan lizardite-based ceramics is technically feasible, economically justifiable and socially desirable due to the contribution to the economic growth of the raw materials sector, especially ceramic industry.

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1. Introduction

In the face of ever-increasing developments and numerous innovations in the ceramic industry, including refractories, the field of mass-market ceramics, in which the wide variety of pyroprotection applications in industry requires a wide diversity of ceramic material supplies. In fact, many of these materials have been developed specifically to meet the operating conditions of a particular process. The characteristic properties of each ceramic class depend on both the raw material used and the manufacturing methods of the ceramic products [1-8]. The type of ceramic to be used is often dictated by the conditions prevailing in the area of application. In the high temperature range, some refractory metal alloys can be used, but their use remains limited below 1000°C. Beyond that, only refractory materials are thermally and mechanically resistant [9].

Today, silica-alumina ceramics are widely used for lining furnaces (refractories), tiles, bricks, ladles, glass tank controllers and secondary refining vessels in ferrous and non-ferrous metallurgy, due to their high degree of refractoriness, high thermal shock resistance and excellent slag resistance [10-11]. At the same time, basic refractories can also be used in various fields as excellent robust material, resistant to heat and electricity, as well as good heat conductor [12]. To date, several research projects have been devoted to the recovery of materials in the field of ceramics, in particular the development and characterization of basic refractory ceramics due to their high refractory quality and their resistance to erosion and corrosion of metals and oxides [13-23].

Due to the growing concern about the economy and the recovery of the basic ceramic industry in Morocco, it is becoming imperative and crucial to look for new raw materials containing magnesium. However, the main focus of discussion only to use three essential minerals forming the rocks: Magnesite, dolomite and lizardite situated in the Rif of Morocco, and which has other secondary materials: perlite, halloysite, diatomite, bentonite and red clays [24-25].

However, detailed studies on Moroccan lizardite-based ceramics are missing. Thus, the present study has been carried out to evaluate the potential use of abundant raw materials from Morocco (i.e., lizardite, magnesite and dolomite) for the preparation of a forsterite-monticellite rich ceramics with the required technical specifications (i.e., high mechanical performances).

2. Materials and Methods

2.1 Collection and Preparation of the Raw Samples

The ultrabasic Beni Bousra massif in the Inner Rif (Morocco) is one of the most important peridotite massifs in the western Mediterranean area. It contains useful geomaterials that can be valorized for ceramic industry. For the purpose of the current study, a lizarditeic clay rich peridotite, dolomite and magnesite samples were collected in the Beni Bousra massif (internal Rif, Morocco) belonging to the Tafidest area to the south-western edge of the Tetouan city (about 103 km SW) (Figure 1). Peridotite from Beni Bousra is an ultrabasic rock which outcrops on the surface in the internal domain of the Rif Alpine range. Peridotite is a plutonic rock of very deep origin (upper mantle) and whose rise and establishment in the crust occur in the context of the retreat of the Alpine subduction towards the South and West during the Oligo-Miocene. The peridotite shows towards the center of the massif a fresh aspect where the rock is bottle-green in color and composed of rounded grains of green olivine distributed over a black background composed of ferro-magnesian minerals (pyroxene, amphibole and biotite) (Figure 2.A). Towards the edge of the massif and along the fractures, the rock becomes weathered and friable (Figure 2.B). Microscopic observation of peridotite shows that olivines and pyroxenes are often cut into fragments (brecciated) and altered into serpentine (antigorite and lizardite). In friable peridotite, there are no longer any primary minerals (olivine and pyroxene); most of the rock is serpentinized.

Magnesite and dolomite were collected from the coordinates N35°13'11.5" W004° 43'49.1" while lizardite clay deposits come from N35° 16'42,9" W004° 51'41.82"). Prior to the different analyses, the collected natural raw materials were hand crushed using a stainless steel mortar and pestle, sieved and a grain size of less than 500 μm was reclaimed and stored in plastic bottles. Further grinding was undertaken when necessary to prepare subsamples for subsequent physico-chemical characterization and ceramic specimen preparation.

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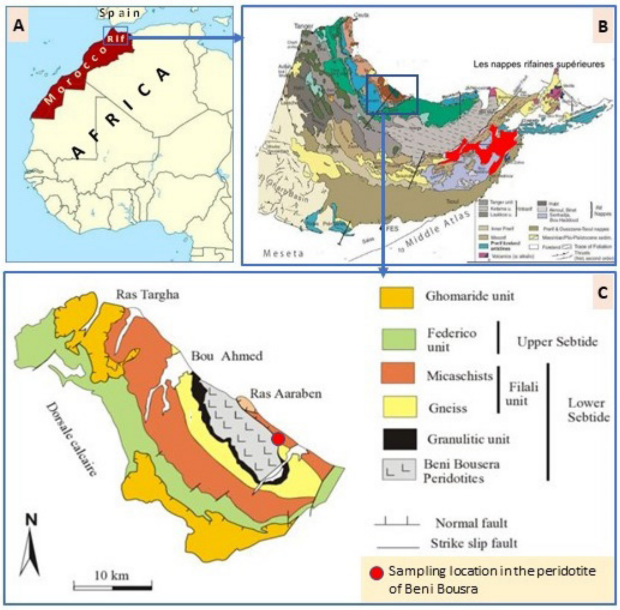

Figure 1. A: Situation of Morocco on the scale of Africa- B: Geological map of the Rif - C: Structural diagram of the environment of the ultrabasic peridotite massif of Beni Bousra with sampling location [26]

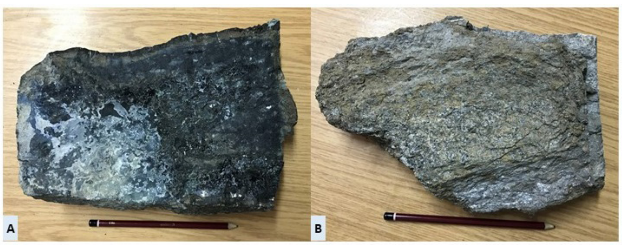

Figure 2. Macroscopic appearance of Beni Bousra's peridotite

2.2 Chemical and Mineralogical Analyses

Chemical compositions of the powdered and pressed samples from the ultrabasic Beni Bousera massif (Morocco) was determined by using a fluorescence spectrometer type 'SPECTRO' (AMETEC company, MOROCCO). XRD analysis was performed on using PANalytical XPert Pro diffractometer equipped with Cu kα radiation (Kα1 = 1.5406 Å, 45 kV and 40 mA). Randomly oriented powder was prepared by sieving 1g of the desired sample (i.e., lizardite, dolomite and magnesite) to 250µm, placed on a sample holder and then step scanned between 2° and 70° (2θ) with 0.02° increments. The diffractogram of each sample was recorded and then computer-processed to get the peak position and its intensity. Abundance of each mineral species present in the studied samples was estimated by the application of the external standard method [27]. FT-IR spectra were obtained with a Bruker Tensor 27 FTIR spectrometer operating in the range 4000–400 cm^{-1}.

Petrographic observation has been performed on thin sections from rock fragments with an optical microscope (Olympus BX 51TF: University Mohammed V, Rabat, Morocco). The texture (shape, size and arrangement of its mineral constituents) and the optical criteria of the minerals (habitus, color, cleavage, pleochroism, relief, polarization tint) allowed a more credible identification of the ubiquitous mineral species. Thin sections of 30 µm thick slide were cut from the desired sample, polished and stick on a glass plate before observation.

2.3 Thermo-dilatometric Analysis

The thermodilatometric test were performed by using a LINSEIS Dilatometer, type: L75 (Linseis Messgeraete GmbH, Selb, Germany) by heating the green ceramic specimen from 25 to 1600 °C at the regular increment of 5 °C/min under air atmosphere. The cycle includes two plateau of 2 h (i.e., 600 and 1200 °C).

2.4 Ceramic Preparation

Technological tests concerned the less than 63 µm sized subsamples that were dried to 105 °C for 24 hours. The dry materials are introduced into jars together with a known weight of stainless-steel balls of various diameters and distilled water (i.e., 4 and 6%). Four mixtures (M1–M4) were prepared by varying lizardite percentages from 10 to 40% (Table 1). About 100 g of the desired mixture was molded in 10 x 5 x 1 cm^3 rectangular shaped mold that was, later, compressed to prepare a green ceramic specimen; cylindrical mini-brick samples were prepared using a hydraulic press (200 bars). The prepared mini-bricks were oven dried for 24 hours and heated to the desired temperatures using an electric furnace (Nabertherm GmbH, Germany) in an oxidizing atmosphere. Heating program was set to a constant heating rate of 3 °C/min with two main plateau of 30 minutes (i.e., 600 and 1100 °C). After firing, the furnace was cooled down to room temperature with a cooling rate of 5 °C/min.

Table 1. Composition of prepared mixtures (wt. %)

Mixtures	Lizardite (%)	Magnesite (%)	Dolomite (%)
M1	10	45	45
M2	20	40	40
M3	30	35	35
M4	40	30	30

2.5 Technological Tests

To find out the main physico-chemical properties of the prepared ceramic specimens, a set of technological tests (i.e., flexural strength, tensile strength, shrinkage) were performed accordingly. Flexural strength measurements were conducted using a 3R type: RP25 ATF. The well-known three-point flexure test was used for testing the prepared ceramic samples according to the ASTM C674-88 normative guideline [28].

Indirect tensile strength (i.e., Brazilian test) was also used to measure the tensile strength of the prepared ceramic specimen using a press apparatus type 3R (SODAP company, Morocco) [29].

Shrinkage test was done by the measurement of the average lengths recorded on mini-brick specimen dried at 110 °C and then fired to 1100 and 1400 °C. The following formula allows the calculation of the firing shrinkage:

$$\text{Shrinkage (\%)}=\frac{L110-Lt}{L110}\times 100 \quad (1)$$

Where Lt is the length after firing and L110 the length after drying at 110 °C.

Linear thermal expansion (α_L in °C^{-1}) was determined by the following relationship:

$$a_L=\frac{\Delta L}{L0\times \Delta T} \quad (2)$$

ΔL: length variation (mm)
L_0: Initial length, expressed (mm).
ΔT: Temperature difference, expressed in K.

A thermal expansion by volume (α_V) can be deduced for an isotropic material from the following relationship [30]:

$$\alpha_V=3\alpha_L \quad (3)$$

The bulk density and apparent porosity were measured according to ASTM C373-88 [31]. In a brief description, a dried test specimen (weight= D; total volume=V) was introduced in a boiling water vessel for 5 h and left to cool down for 24h to determine the saturated mass (M). Finally, the Apparent porosity, P (%), was calculated as follows:

$$P=\frac{M-D}{V}\times 100 \quad (4)$$

Bulk density, B (g/cm^3), included pores as follows:

$$B=\frac{D}{V} \quad (5)$$

Microstructural analysis of the prepared ceramics specimens was conducted by scanning electron microscope coupled with the EDS analysis, type: Hitachi TM3000.

3. Results and Discussion

3.1 Characterization of the Raw Samples

Chemical composition, by XRF (Table 2), showed that magnesite was mainly composed of MgO (42.63%). Such a carbonaceous natural sample exhibited a high loss on ignition (LOI = 52.35%) due to its $MgCO_3$ content. Dolomite showed a similar high LOI value (51.02%), but lower MgO content (20.63%) compared to magnesite. In addition, it was expected to find higher percentage of $CaCO_3$ (40.57%), as a further proof about the dolomitic nature of the collected carbonate sample (i.e., dolomite sample). SiO_2 contents in both materials were ascertained to 1.78% and 3.06% for magnesite and dolomite, respectively. Low amounts of alumina (Al_2O_3) were found in both samples. In contrast, lizardite sample showed a predominant silica content, reaching 53.48%; followed by a relatively high magnesia content (35.39%), iron oxide (6.68%) and alumina (3.15%) together with faint amounts of Na_2O (0.9%) and CaO (0.33%). Such a chemical composition perfectly corroborated with the mineralogical composition of lizardite (predominant mineral phase).

Figure 3 represents the positions of the used raw materials on the CaO-SiO_2-MgO ternary diagram. A number

Table 2. Chemical analysis by X-ray fluorescence of raw materials (wt. %)

Samples	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	K_2O	Na_2O	P_2O_5	MnO	SO_3	TiO_2	LOI
Dolomite	3.06	1.96	0.13	20.63	22.73	0.06	0.19	0.02	0.01	0.06	0.13	51.02
Magnesite	1.78	0.89	0.09	42.63	2.03	0.03	0.13	0.01	--	--	0.06	52.35
Lizardite	53.48	3.15	6.68	35.39	0.33	0.03	0.90	--	--	--	0.04	--

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of investigations dealing with one or more of the three oxides: lime, magnesia and silica, have in recent years been carried out, as a preliminary step in the study of the rocks and minerals of the earth's crust. These studies include all of the possible binary and ternary of the CaO-SiO_2-MgO systems. The phases which occur in the ternary system are: (1) Cristobalite, SiO_2, (2) Tridymite, SiO_2, (3) Pseudowollastonite, α CaO.SiO_2, (4) Tricalcium di-silicate, 3CaO. 2SiO_2, (5) α Calcium orthosilicate, α 2CaO. SiO_2, (6) Lime, CaO, (7) Periclase, MgO, (8) Forsterite, 2MgO.SiO_2, (9) monticellite, (CaO.MgO.SiO_2), (10) Diopside, (CaO.MgO.2SiO_2) and (11) pyroxene solid solution [32].

Nevertheless, it can be noted that if the MgO and SiO_2 amount increases, new phases such as forsterite and monticellite will appear. The used carbonate raw materials (magnesite, dolomite and lizardite) decomposed into monoxide, in combination with SiO2, form new phases such as forsterite (2MgO.SiO_2), monticellite (CaO.MgO. SiO_2) and diopside (CaO.MgO.2SiO_2) [33]. Olivine could also be observed as an intermediate phase before forsterite formation occurs, depending on the relative proportions of the three components (SiO_2, MgO, CaO) and the firing temperature.

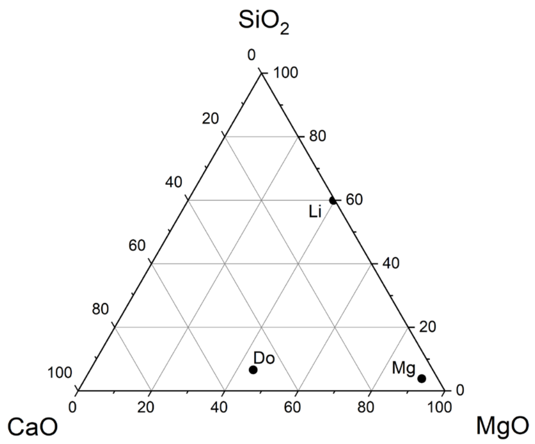

Figure 3. Classification of the studied raw materials based on CaO-SiO_2-MgO ternary diagram (Li: Lizardite, Do: Dolomite and Mg: Magnesite)

As shown in Figure 4, lizardite sample contains lizardite and antigorite phases. Dolomite sample is composed mainly of dolomite mineral as major element as well as periclase, quartz, chlorite and goethite as minor components. The magnesite sample is composed essentially of magnesite minerals. Reflections of periclase, chlorite were also observed with low intensity peaks [34]. Those observations were confirmed by the semi-quantified estimations (Table 3).

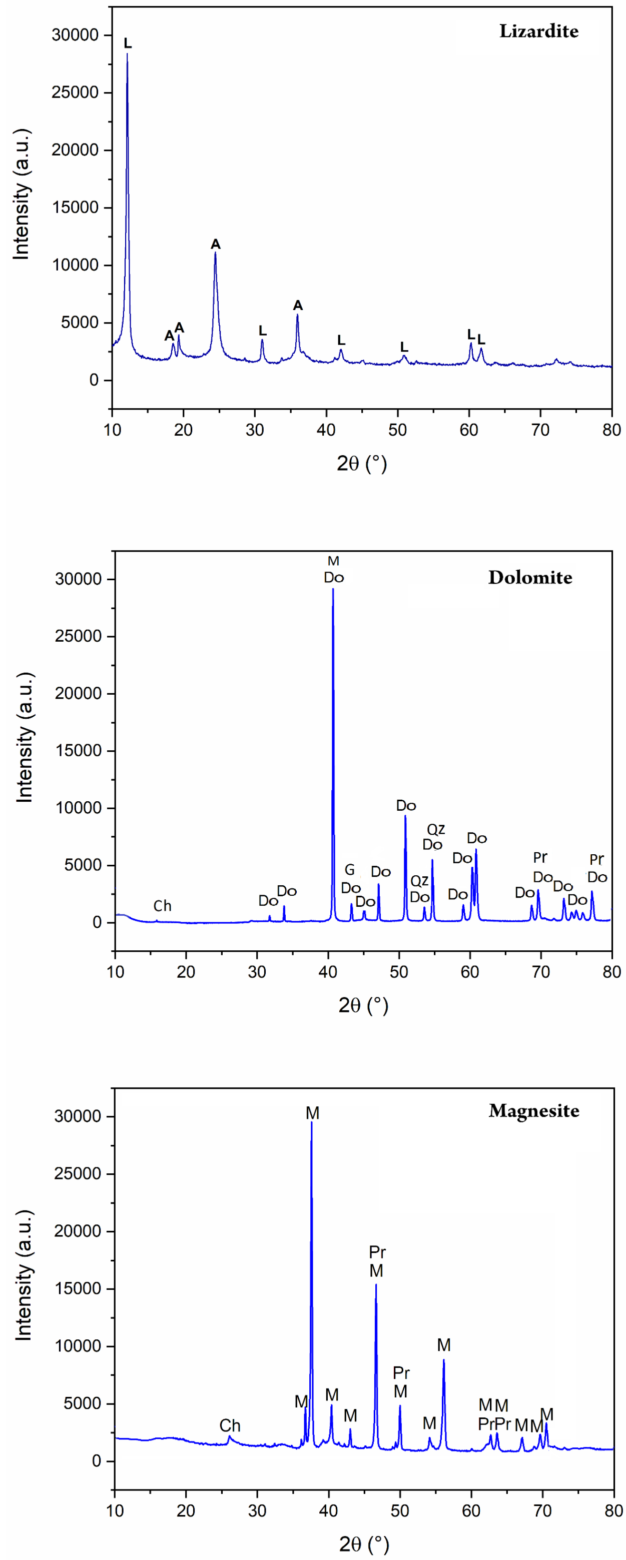

Figure 4. X-ray diffractograms of the studied Lizardite (a), Dolomite (b) and Magnesite (c). L: Lizardite, A: Antigorite, Qz: Quartz, Do: Dolomite, M: Magnesite, Pr: Periclase, G: Goethite, Ch: Chlorite)

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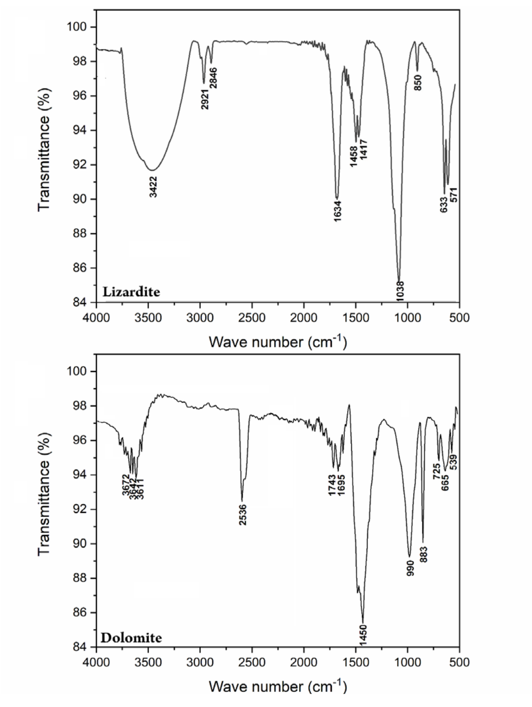
Table 3. Semi-quantitative analysis of the studied raw materials based on XRD diffractograms (%)

	Lizardite	Antigorite	Quartz	Dolomite	Magnesite	Goethite	Periclase	Total
Lizardite	67.12	30.69	1.69	-	-	-	-	99.5
Dolomite	-	-	3.9	74.2	-	0.8	20	98.9
Magnesite	-	-	-	2.5	80.5	-	16.8	99.8

IR spectra given in Figure 5, showed the main characteristic bands of lizardite, dolomite and magnesite samples. Lizardite IR spectra showed the presence of a small amount of organic matter due their characteristic bands at 2846 and 2921 cm^{-1} [35]. A broad band at about 3422 cm^{-1} showed the presence of sepiolite (Si-O-Mg vibration) [36]. Iron hydroxide vibrated between 571 and 633 cm^{-1}; Si-O band near 1038 cm^{-1}. The bands attributed to deformation of C-O groups (i.e., carbonates) can be observed at 850 and 1458 cm^{-1} [33]. Concerning dolomite sample, wide bands observed near 1695, 3611, 3642 and 3672 cm^{-1} were attributed to the vibration mode of O-H groups. Moreover, the presence of dolomite has been confirmed by three characteristic bands near 725, 1743 and 2536 cm^{-1} in dolomite and magnesite materials. Another band at 1506 cm^{-1} in the magnesite spectrum suggested C-O bending [37]. At a lower frequency range, bands detected at 538, 598, 640 and 990 cm^{-1} are assigned to the Si-O-Mg vibrations. Two bands at 883 and 1450 cm^{-1} are also observed, as they correspond to the bands of the Mg-O bonds [38-39].



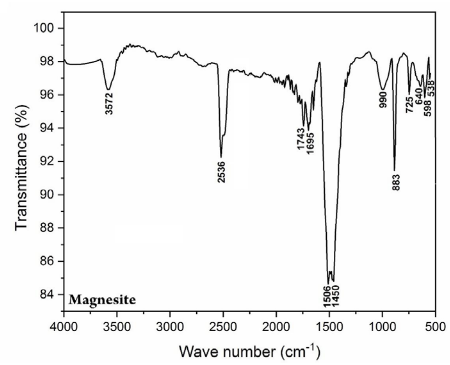
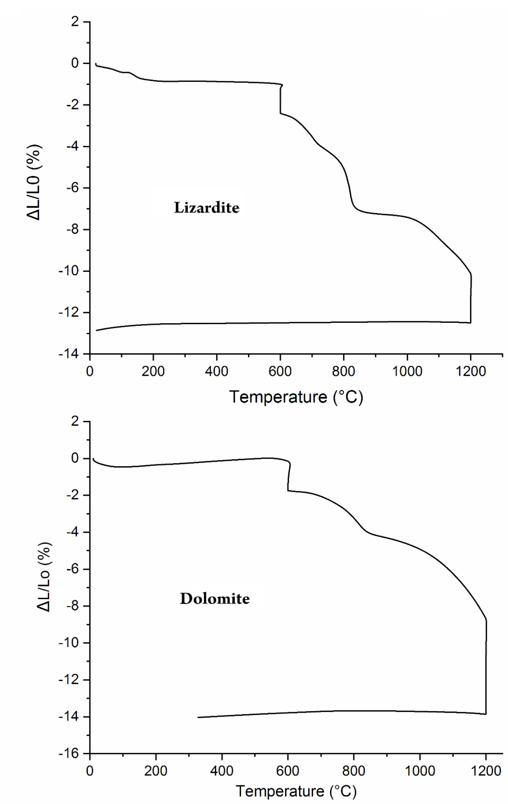


Figure 5. FTIR spectra of the studied lizardite (a), dolomite (b) and magnesite samples (c)

Dilatometric analysis of magnesite and dolomite, after heat treatment up to 1200°C, showed a clear difference in their shrinkage behaviors (Figure 6). Dilatometric curves of magnesite and dolomite showed similar trends with a first shrinkage, occurred between 600°C and 825°C, due to the decomposition of carbonates. Then, the transformation to periclase started from 850°C upwards. A total drop around 1200°C indicated a structural rearrangement of periclase. It can be seen that the shrinkage was far larger than the expansion rate (ΔL/L0 was -14% and -15% for dolomite and magnesite, respectively). Similar behavior was observed for lizardite sample, but to a somewhat lower extent (-13%).



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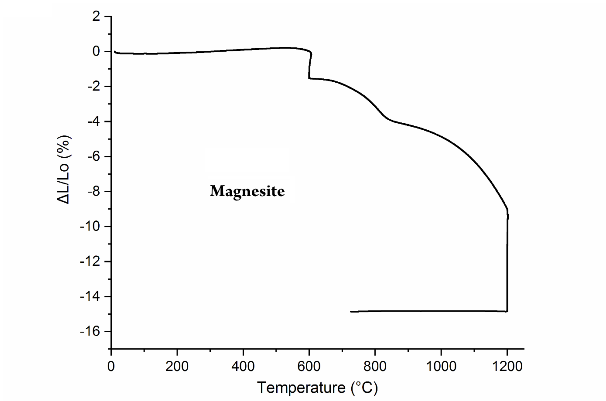
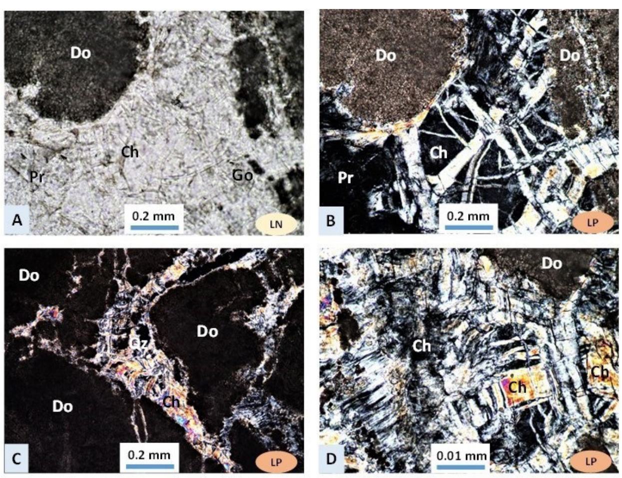
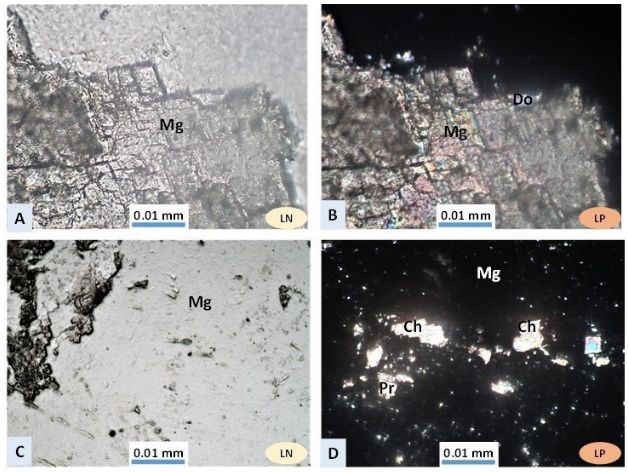


Figure 6. Thermodilatometric curves of the studied natural samples

Microscopic observations of the prepared thin sections indicated dominant dolomite minerals (Figure 7.a); a heterogeneous texture composed of finely graded masses of dolomite cut by veins of secondary alteration products. Micrographs A and B taken respectively in natural light (LN) and polarized light (LP) show the finely graded mass of dolomite recognizable by its high polarization (of the 3rd and 4th order on the Newton chromatic scale). High magnification revealed that the late veinlets crossing the dolomite mass were mainly composed of chlorite, periclase, quartz and some opaque grains (i.e., iron oxides: goethite). Magnesite sample showed a granoblastic texture with millimeter-sized joined grains of magnesite minerals (Figure 7.b). Magnesite is recognizable on both micrographs A and B by its almost orthogonal double cleavage and its high polarization shades with pink and green iridescence. At high magnifications, the magnesite grains showed small muscovite/chlorite flakes, calcite, periclase and rare opaque grains of hematite or goethite as accessory minerals. It should be noted that the mineralogical compositions of the both samples (Dolomite and Magnesite), revealed by optical microscope observations, corroborate XRD data.



Dolomite sample



Magnesite sample

Figure 7. Microscopic observation of thin section from the dolomite (a) and magnesite samples (b) (LN: natural light, LP: Polarized light - Do: dolomite; Mg: Magnesite; Ch: Chlorite; Go: Goethite; Pr: Periclase; Qz: Quartz)

3.2 Characterization of Ceramics

Mineralogical analysis, by XRD, of the prepared ceramic samples is shown Figure 8. It is obvious that the dolomite and magnesite decomposed to free magnesia, and transformed to forsterite in the range of 780–1400 °C [40]. XRD pattern of M1 sample (10% of lizardite) showed a predominant periclase with traces of montecellite and calcium-alumino-ferrite phase. Porous oxides are formed during the decomposition of dolomite with a variation in molar volumes ranging from 62.94 cm^3 mol^{-1} for $CaMg(CO_3)_2$ to 16.92 cm^3 mol^{-1} for CaO and 11.26 cm^3 mol^{-1} for MgO. After calcination, the resulting oxides have lower molar volumes, larger surfaces and greater porosity than carbonates. The thermal decomposition of dolomite and magnesite are similar [41-43]:

$$CaMg(CO_3)_2 <===> CaCO_3 + MgO + CO_2 \quad (6)$$

$$CaCO_3 <===> CaO + CO_2 \quad (7)$$

An endothermic reaction corresponded to magnesite decomposition occurs from 800 °C. Its calcination reaction can written as follow:

$$MgCO_3 <===> MgO + CO_2 \quad (8)$$

XRD diffractograms of the prepared samples (i.e., M2, M3 and M4) are mainly composed of forsterite and monticellite, with a minor periclase, cristobalite and olivine. The intensity peak of forsterite slightly increases with lizardite addition. The presence of those new phases gave the sintered mixtures enhanced physico-chemical proper-

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ties with respect to the original raw materials.

Figure 9 showed the relative content of forsterite formation of M1-M4 series samples after firing at temperatures in the range of 1100–1400 °C for 2 h. The forsterite content exceeded 13.8 wt% in sample M4 after firing at 1100 °C, whereas the forsterite was absent in sample M1. After firing at 1400 °C, the relative content of the forsterite in sample M4 reached 42.7 wt% but remained at only 25.9 wt% in the sample M1. The relative content of forsterite in the sample M4 was greater than that in sample M1, M2 and M3 under the same firing temperature. This result indicates that finer lizardite powders contributed to a higher rate of forsterite formation. We conclude that the smaller lizardite particles enhanced the kinetics of the solid-state reactions and accelerated the rate of forsterite formation.

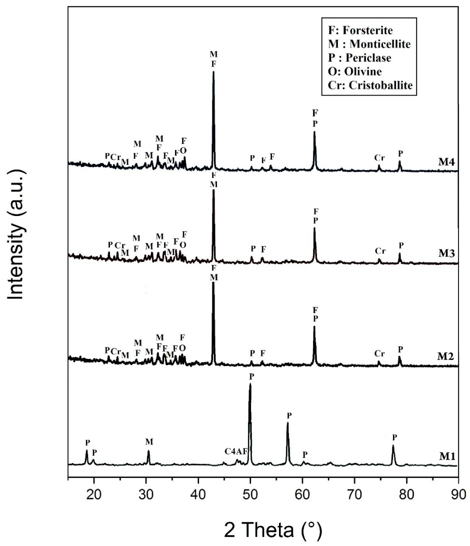


Figure 8. XRD patterns of the prepared mixtures at 1400 °C

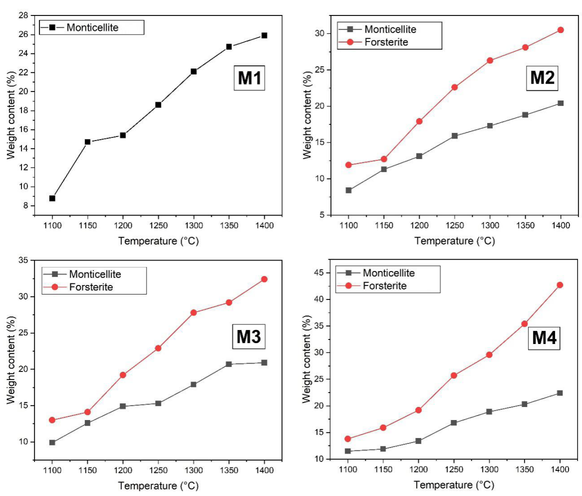
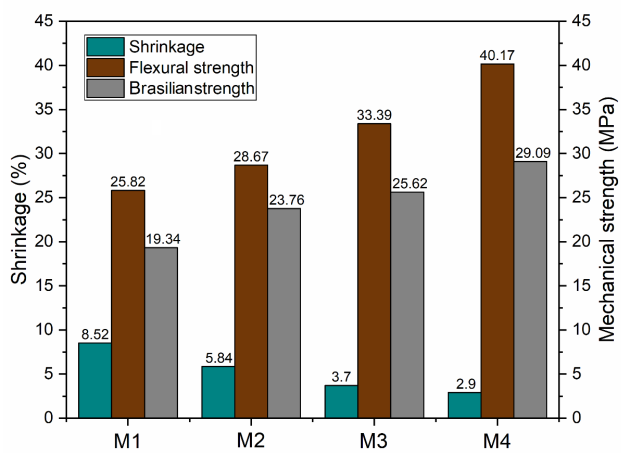


Figure 9. Relative content of forsterite and monticellite in M1-M4 mixtures after firing to the temperatures range of 1100–1400 °C for 2 h

Technological properties of fired mixtures were reported in Figure 10. An increased amount of lizardite in the initial mixtures stimulated the formation of more liquid phase upon calcination. The obtained results indicated that the prepared mixtures had increasing flexural strengths with augmented lizardite content. M4 sample recorded the highest flexural strength of 40.17 MPa. Data showed that firing shrinkage reached 8.52% for M1, but the addition of lizardite has led to a decrease in linear shrinkage during calcination up to 1400 °C. Low firing shrinkage values were observed for M2 (5.84%), M3 (3.7%), and M4 (2.9%).

The results of the Brazilian test varied between 19.34 MPa for M1 and 29.09 MPa for M4. Those value clearly satisfy the required technical specifications for ceramic industry. Such an increased consolidation may confirm the positive effects of lizardite addition via the activation of densification process which enhanced mechanical strength of the prepared ceramic mixtures. Figure 10.b shows the variation in bulk density and porosity as a versus lizardite contents of the prepared mixtures. It can be easily observed that M1 has the lowest bulk density (1.63 g/cm^3); that of M4 reached 3.25 g/cm^3. Similar results were obtained in previous studies [44-46]. In contrast, porosity decreased with bulk density. M1 yielded a porosity of 4.43% that decreased for M2, M3, M4, reaching 3.35, 1.9, and 0.89%, respectively. This can be attributed to the increase of the liquid phase with lizardite addition that directly affect the existing pore. Linear thermal expansion coefficients of all samples (i.e., M1, M2, M3 and M4) were ascertained of α_{M1}=1.7x10^{-5}/°C, α_{M2}=1.5x10^{-5}/°C, α_{M3}=1.25x10^{-5}/°C and α_{M4}=1.07x10^{-5}/°C). These results are in favor of good quality ceramics (Table 4).



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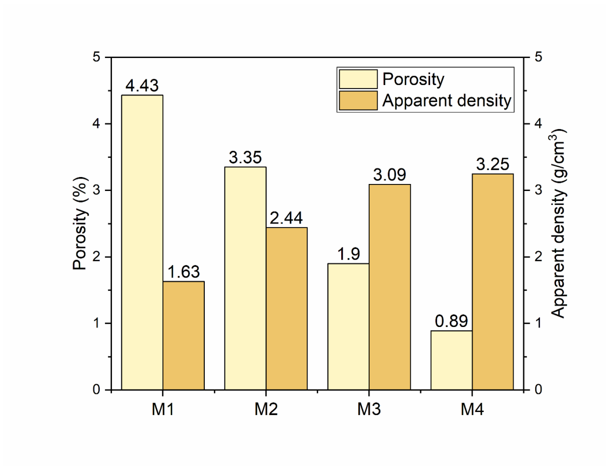

Figure 10. Technological properties of fired specimens at 1400 °C. a) Mechanical properties and b) Porosity and bulk density

Table 4. Thermal expansion coefficients of the fired specimens at 1400 °C/30 min

Samples	α_L (10^{-5}/°C)	α_V (10^{-5}/°C)
M1	1.70	5.10
M2	1.50	4.50
M3	1.25	3.75
M4	1.07	3.21

On the other hand, the tested samples have maintained their shape without undergoing any deformation up to 1400 °C (Figure. 11). They retain their original characteristics: no cracks, no deformation and low shrinkage at the end of the thermal cycle. The coloration is increasingly dark towards M4, which is due to the increase of iron oxides present in the started lizardite sample (6.68 %).

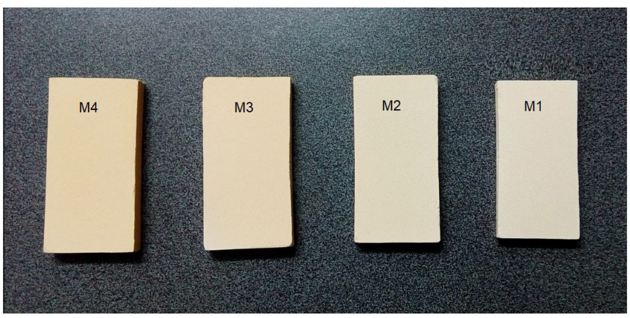

Figure 11. Aspect of samples fired at 1400 °C

The microstructure of the fired samples, having different content of lizardite were analysed using SEM. The micrographs shown in Figure 12 demonstrate significant effect of lizardite on the size and distribution of the particles on the surface. The surface morphologies of the samples are marked by the existence of particles with different grain sizes (1-10 μm) and distributions. The observation show that the formation of forsterite phase is highest in M4, supported by XRD analysis (Figure 9). Increase in grain size of forsterite, that is proportional to the amount of lizardite added, causes decrease in porosity (Figure 13), and subsequently, improving the mechanical properties ceramics (i.e., the flexural strength and Brazilian test).

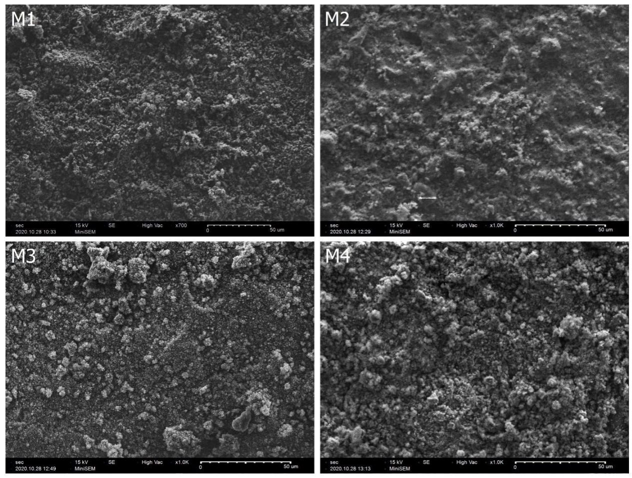

Figure 12. SEM micrographs of the mixtures fired at 1400 °C

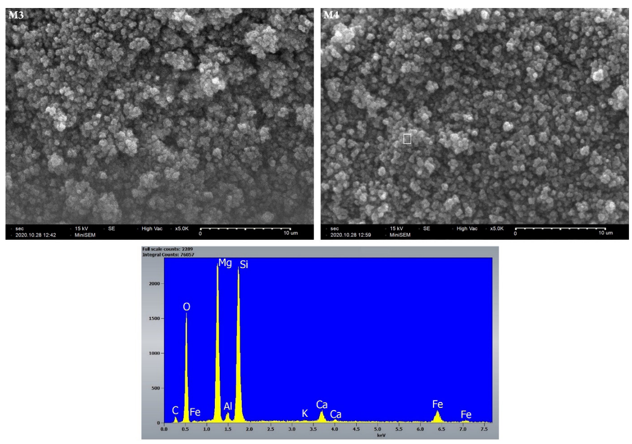

Figure 13. Microstructural analysis showing the porosity evolution by the SEM-EDS

4. Conclusions

This study has been carried out to evaluate the potential use of natural deposits from morocco for ceramic industry; the application concerned the Beni Bousra Massif (Rif domain, Southwestern Morocco) that showed important deposits of lizardite, magnesite and dolomite. Mineralogical analysis by X-ray diffraction on ceramic specimen from different mixtures confirmed the formation and co-

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existence of forsterite (Mg_2SiO_4) and monticellite ($CaMgSiO_4$). SEM observations showed increased densifications with temperature up to 1400 °C, proving that the addition of lizardite activated densification that contribute to the enhanced technological properties. An increased lizardite addition has led to a decrease in the linear shrinkage during calcination to 1400 °C.

Finally, the economic and social interest through the valorization of the numerous deposits will undoubtedly contribute to the sustainable development of this area. The preparation of lizardite-based ceramics was feasible with required technological properties, making from the Rif area a potential supplier of natural materials for ceramic industry.

CRediT authorship contribution statement

Ahmed Manni: Methodology, original draft, Laboratory operations.

Achraf Harrati: Methodology, original draft, Laboratory operations.

Abdelilah El Haddar: Sampling of raw material.

Abdelwahed Chari: Laboratory physico-chemical analysis (DRX and SEM).

Ali Sdiri: Writing manuscript and Revision.

Fahd Oudrhiri Hassani: Laboratory analysis (Thermodilatometric analysis), Reading manuscript and Revision.

Abdeslam El Bouari: Supervision and Validation.

Iz-Eddine El Amrani El Hassani: Study of the geological part and preparation of thin sections for observation under a microscope.

Chaouki Sadik: Scientific Direction, Results interpretation, Recommendations, Writing manuscript and Revision.

References

[1] C. Sadik, I. El Amrani, A. Albizane. Influence de la nature chimique et minéralogique des argiles et du processus de fabrication sur la qualité des carreaux céramiques. MATEC Web of Conferences, 2012, 2, Article ID: 01016.

[2] C. Sadik, I. Amrani, A. Albizane. Effect of carbon graphite on the crystallization of andalusite: Application to the synthesis of mullite and the improvement of refractory quality. Materials Sciences and Applications, 2013, 4(6): 337-346.

[3] C. Sadik, I. El Amrani, A. Albizane. Composition and ceramic characteristics of cretaceous clays from Morocco. Advances in Science and Technology, 2014, 92: 209-214.

[4] A. Harrati, A. Manni, A. El Bouari, I. El Amrani El Hassani, C. Sadik. Elaboration and thermomechanical characterization of ceramic-based on Moroccan geomaterials: Application in construction. Materials Today: Proceedings, 2020, 30: 876-882.

[5] C. Sadik, A. Manni, S. El Kalakhi, I. El Amrani, Preparation and characterization of possible basic ceramics from Moroccan magnesite. J Aust Ceram Soc, 2019, 55: 415-423.

[6] C. Sadik, I. El Amrani, A. Albizane. Processing and characterization of alumina-mullite ceramics. Journal of Asian Ceramic Societies, 2014, 2: 310-316.

[7] C. Sadik, I. Amrani, A. Albizane. Composition and refractory properties of mixtures of Moroccan silica-alumina geomaterials and alumina. New Journal of Glass and Ceramics, 2013: 59-66.

[8] A. Manni, B. Achiou, A. Karim, A. Harrati, C. Sadik, M. Ouammou, S. Alami Younssi, A. El Bouari. New low-cost ceramic microfiltration membrane made from natural magnesite for industrial wastewater treatment. Journal of Environmental Chemical Engineering, 2020, 8: 103906.

[9] C. Sadik, I. El Amrani, A. Albizane. Recent advances in silica-alumina refractory: A Review. Journal of Asian Ceramics Societies, 2014, 2: 83-96.

[10] A. Harrati, A. Manni, F.O. Hassani, A. Sdiri, S. El Kalakhi, A. El Bouari, I. El Amrani El Hassani, C. Sadik. Potentiality of new dark clay-rich materials for porous ceramic applications in Ouled Sidi Ali Ben Youssef Area (Coastal Meseta, Morocco). Journal of the Spanish Ceramic and Glass Society. In press.

[11] D.A. Brosnan, Alumina-silica brick, in: C.A. Schacht (Ed.), Refractories Handbook, Marcel Dekker Inc., New York, 2004: 79-107.

[12] C. Sadik, I. El Amrani, O. Moudden, A. El Bouari. Review on the elaboration and characterization of ceramics refractories based on magnesite and dolomite. Journal of Asian ceramics Societies, 2016, 4: 219-233.

[13] F. Wang, J. Ye, G. He, G. Liu, Z. Xie, J. Li. Preparation and characterization of porous MgAl2O4 spinel ceramic supports from bauxite and magnesite. Ceram. Int, 2015, 41: 7374-7380.

[14] Ghosh, C., Ghosh, A., Tripathi, H.S., Ghosh, J., Haldar, M.K. Studies on densification, mechanical, microstructural and structure–properties relationship of refractory aggregates prepared from Indian magnesite by changing lime–silica ratio. Ceram. Int, 2014, 40(16791-16798.

[15] Burhanuddin, A.,Kumar, P., Kumar, A.,Ghosh, S., Sinhamahapatra, S., Tripathi, H.S. Effect of zirconia on densification and properties of natural Indian

  DOI: https://doi.org/10.30564/jcr.v2i1.2684

magnesite. Int. J. Miner. Process, 2015, 144: 40-45.

[16] Serry, M.A., El-Kholi, M.B., Elmaghraby, M.S., Telle, R. Characterization of Egyptian dolomitic magnesite deposits for the refractories industry. Ceram. Int, 2002, 28: 575-583.

[17] Rabah, M., Ewais, E.M.M. Multi-impregnating pitch-bonded Egyptian dolomite refractory brick for application in ladle furnaces. Ceram. Int, 2009, 35: 813-819.

[18] Ewais, E.M.M., Bayoumi, I.M.I., El-korashy, S.A. M-CZ composites from Egyptian magnesite as a clinker to RCK refractory lining. Ceram. Int, 2018, 44: 2274-2282.

[19] Saha, A., Singh, S.K., Ghosh, A., Ghosh, J., Haldar, M.K. Studies on synthesis and properties of magnesia refractory aggregates prepared from Indian magnesite through plasma fusion. Ceram. Int, 2015, 41: 2876-2883.

[20] Sinhamahapatra, S., Tripathi, H.S., Ghosh, A. Densification and properties of magnesia-rich magnesium-aluminate spinel derived from natural and synthetic raw materials. Ceram. Int, 2016, 42: 5148-5152

[21] Nan,W., Min, C., Yue-yuan, L., Hong-wei, N. Preparation of MgO whisker from magnesite tailings and its application. Trans. Nonferrous Metals Soc. China, 2011, 21: 2061-2065.

[22] Yuna, Z., Guocai, Z. A technology of preparing honeycomb-like structure MgO from low grade magnesite. Int. J. Miner. Process, 2014, 126: 35-40.

[23] Thomaidis, E., Kostakis, G. Synthesis of cordieriticmaterials using raw kaolin, bauxite, serpentinite/olivinite and magnesite. Ceram. Int, 2015, 41: 9701-9707.

[24] A. El Haddar, A. Manni, A. Azdimousa, I. El Amrani El Hassani, A. Bellil, C. Sadik, N. Fagel, M. El Ouahabi. Elaboration of a high mechanical performance refractory from halloysite and recycled alumina. Journal of the Spanish Ceramic and Glass Society, 2020, 59: 95-104.

[25] M. El Ouahabi, L. Daoudi, F.D. Vleeschouwer, R. Bindler, N. Fagel. Potentiality of Clay Raw Materials from Northern Morocco in Ceramic Industry: Tetouan and Meknes Areas, J. Min. Mat. Char. Eng, 2014, 2: 145-159.

[26] Kornprobst, J. Contribution à l'étude pétrographique et structurale de la zone interne du Rif, Notes et Mém. Serv. géol. Maroc, 1974, 251, 256.

[27] G.W. Brindley. Quantitative X-ray mineral analysis of clays. In: Brindley, G.W., Brown, G. (Eds.), Crystal Structures of Clay Minerals and Their X-ray Identification, Monograph 5. Mineralogical Society, London, 1980: 411-438.

[28] ASTM C674-88, Standard test methods for flexural properties of ceramic whiteware materials.

[29] R. H. Marion et K. Johnstone, A parametric study of the diametral compression test of ceramics, Am. Ceram. Soc. Bull, 1977, 56: 998.

[30] Fei Zhao, Lixin Zhang, Zhen Ren, Jinxing Gao, Xiaoyu Chen, Xinhong Liu, Tiezhu Ge. A novel and green preparation of porous forsterite ceramics with excellent thermal isolation properties. Ceramics International, 2019, 45: 2953-2961.

[31] ASTM C373-88, Standard test method for water absorption, bulk density, apparent porosity, and apparent specific gravity of fired whiteware products, Glass Ceramic, 2006: 15-02.

[32] J. B. Ferguson, H. E. Merwin. The Ternary System CaO-MgO-SiO2. Proceedings of the National Academy of Sciences of the United States of America, 1919, 5(1):16-18.

[33] M. Hajjaj, Mineralogy and thermal transformation of clay materials from the district of Marrakech, Morocco, Comunicações Geológicas, 2014, 101(1):75-80.

[34] Abi, C. E., Gürel, S. B., Kılınç, D., Emrullahoglu, Ö. F. Production of forsterite from serpentine–Effects of magnesium chloride hexahydrate addition. Advanced Powder Technology, 2015, 26(3): 947-953.

[35] Bain, D. C., Fraser, A. R. An unusually interlayered clay mineral from the eluvial horizon of a humus-iron podzol. Clay Minerals, 1994, 29:69-76.

[36] Manni, A., El Haddar, A., El Hassani, I. E. E. A., El Bouari, A., Sadik, C. Valorization of coffee waste with Moroccan clay to produce a porous red ceramics (class BIII). Boletín de la Sociedad Española de Cerámica y Vidrio, 2019.

[37] İ. Kıpçak, T.G. Isıyel, Magnesite tailing as low-cost adsorbent for the removal of copper (II) ions from aqueous solution, Korean J. Chem. Eng, 2015, 32: 1634-1641.

[38] M.B. Gawande, P.S. Branco, K. Parghi, J.J. Shrikhande, R.K. Pandey, C.A.A. Ghumman, N. Bundaleski, O.M.N.D. Teodoro, R.V. Jayaram, Synthesis and characterization of versatile MgO–ZrO2 mixed metal oxide nanoparticles and their applications, Catal. Sci. Technol, 2011, 1: 1653.

[39] Gopinath, D., Gunasekaran, S. The FTIR Spectra of Raw Magnesite and Sintered Magnesite, International Journal of Trend in Scientific, 2018, 2(4). ISSN No: 2456-6470.

[40] T.W. Cheng, Y.C. Ding, J.P. Chiu. A study of synthetic forsterite refractory materials using waste serpentine cutting. Minerals Engineering, 2002, 15: 271-275.

[41] Hartman M, Trnka O, Vesely V, Svoboda K. Predicting the rate of thermal decomposition of dolomite. Chem Eng Sci, 1996, 51: 5229-32.
[42] Kristo´f-Mako E, Juha´sz AZ. The effect of mechanical treatment on the crystal structure and thermal decomposition of dolomite. Thermochim Acta, 1999, 342: 105-14.
[43] Fazeli AR, Tareen JAK. Thermal decomposition of rhombohedral double carbonates of dolomite type. J Therm Anal Calorim, 1991, 37, 2605-11.
[44] Zussman, J., R. Howie, W. Deer, An introduction to the rock forming minerals, Longman, UK, 1992.
[45] Soga, N., ANDERSON, O. L. High-temperature elasticity and expansivity of forsterite and steatite. Journal of the American Ceramic Society, 1967, 50(5): 239-242.
[46] Bafrooei, H. B., Ebadzadeh, T., Majidian, H. Microwave synthesis and sintering of forsterite nanopowder produced by high energy ball milling. Ceramics International, 2014, 40(2): 2869-2876.

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ARTICLE

Elasto-plastic Analysis of High-strength Concrete Shear Wall with Boundary Columns Using Fiber Model

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ABSTRACT

In this study, an experimental study and numerical calculations using fiber model were conducted for four high-strength concrete shear walls with boundary columns under low cyclic load. The boundary column and shear wall were divided into fiber elements, and PERFORM-3D finite element analysis software was used to carry out push-over analysis on the test specimens. The results show that the finite element analysis results were in good agreement with the experimental results. The proposed analysis method could perform elasto-plastic analysis on the high-strength concrete shear wall with boundary columns without distinguishing the categories of frame column and shear wall. The seismic performance of high-strength concrete shear wall with boundary columns was analyzed using the following parameters: axis compression ratio, height to width ratio, ratio of vertical reinforcement, and ratio of longitudinal reinforcement in the boundary column. The results show that the increase in the axial compression ratio causes the bearing capacity of the shear wall to increase at first and then to decrease and causes the ductility to decrease. The increase in the height to width ratio causes the bearing capacity of the shear wall to decrease and its ductility to increase. The ratio of vertical reinforcement was found to have little effect on the bearing capacity and ductility. The increase in the ratio of longitudinal reinforcement in boundary column resulted in a significant increase in the bearing capacity and caused the ductility to decrease at first and then to slowly increase.

1. Introduction

Use italic for emphasizing a word or phrase. Do not use boldface typing or capital letters except for section headings (cf. remarks on section headings, below). As the name implies, high-strength concrete exhibits very high-strength. In addition it has several other advantages, such as high elastic modulus, durability, good impermeability, and leak resistance. High-strength reinforced concrete used in high-rise and super high-rise buildings can reduce the size of the shear wall section and the structure weight. However, high-strength concrete is very brittle and causes a poor deformation ability of the shear wall. Therefore, improving the seismic behavior of high-strength concrete shear walls is very important. Studies showed that the seismic performance of high-strength concrete shear walls could be effectively improved by setting boundary columns at both ends of the wall [1].This approach was

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found also to improve the wall's ductility index to meet the design requirements. The common analysis methods of shear walls with boundary columns are to equate the column with the wall or to separate the wall and column. One disadvantage of the later is that the deformation coordination of wall and column elements in the adjacent boundary cannot be guaranteed and the bearing capacity of members is underestimated [2]. In this study, PERFORM-3D finite element software and fiber model were used to perform nonlinear numerical simulation of high-strength concrete shear wall with boundary columns. This is a nonlinear analysis method for high-strength concrete shear walls with side columns, which can be used in engineering applications, because it can meet the engineering requirements with sufficient accuracy.

Establishment of Numerical Model

PERFORM-3D software, formerly known as the Drain-3D program, was developed by Professor Powell from the University of California, Berkeley [3]. It mainly uses fiber unit model to perform seismic elasto-plastic analysis of complex and super high-rise buildings. PERFORM-3D adopts fiber wall unit to be used with shear walls. Axial-bending characteristics of shear walls are represented by concrete fiber and reinforcement fiber sections. Shear characteristics are represented by elastic or elasto-plastic shear materials. In PERFORM-3D, the shear wall unit based on the fiber model is constructed according to the multi-vertical bar element model (MVLEM) theory [4] (Fig.1). The fiber wall element satisfies the assumption of flat section, and hence the upper and lower parts of the element are always rigid rods that are used to maintain the plane. Vertical spring k_{v1},k_{v2}... k_{vn} simulates the bending effect of the entire wall section, and the horizontal spring k_s simulates the shear dislocation deformation at the top and bottom.

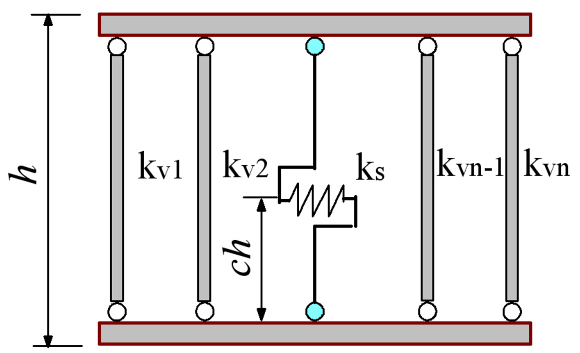

Figure 1. Schematic diagram of the MVLEM unit

PERFORM-3D shear wall fiber model separately defines reinforcement and concrete fiber units and then assembles them. The end restraint area can be simulated using confined concrete fiber. The shear wall with boundary column analyzed in this study divided both boundary column and shear wall into fiber elements (Fig.2) without distinguishing between the column and the wall components. In the shear wall simulation, the vertical grid division was carried out for the height of the shear wall. The length of the vertical elements is determined based on the FEMA356 recommendation [5], taking half of the wall length. The axial force was applied to the joint at the top of the wall.

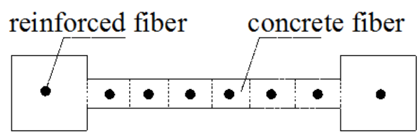

Figure 2. Fiber section division

2. Material Constitutive Model

2.1 Concrete

The boundary column concrete was simulated using the Mander constrained concrete constitutive model [6]. The concrete in the web part was considered to be unconstrained and was modeled according to the stress-strain curve provided in appendix C of *Code for design of concrete structures* [7]. However, tensile strength was not considered in both restrained and unrestrained concretes.

PERFORM-3D software restricted that the concrete constitutive curve can only be composed of multiple broken lines, as shown in Fig.3. In Fig.3, Y is the yield point, U is the peak point, UL is the transient horizontal segment, L is the beginning of the stress decline, R is the residual stress value, and X is the material maximum deformation point. In this study, the constitutive relationship of concrete was fitted assuming that the enclosed area under the broken line segment and the enclosed area under the Code curve were equal [8]. In addition, initial stiffness of the broken line is assumed to be the value of the elastic modulus.

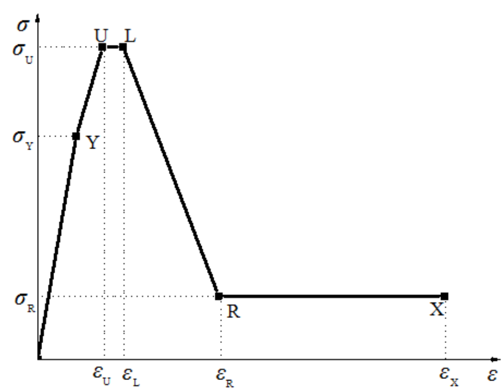

Figure 3. Concrete multi-line constitutive relationship under axial compression

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2.2 Rebar

The rebars were simulated according to the three-fold constitutive model (Fig.4), where f_Y is the yield strength, f_U is the ultimate strength, and the stiffness reinforcement coefficient is 0.01.

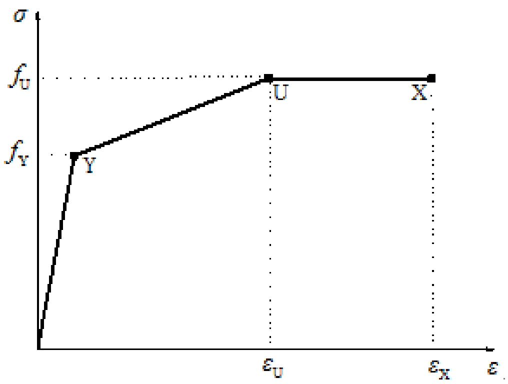
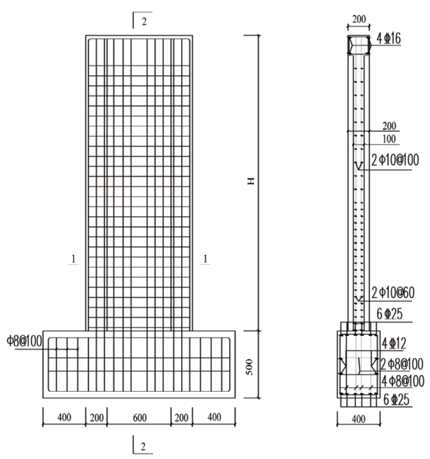


Figure 4. Reinforcement constitutive relationship

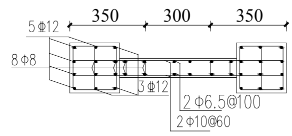
3. Calculation Results and Parameter Analysis

3.1 The Experiment

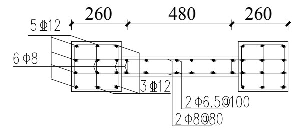
Following reference [1], four high-strength concrete shear walls with boundary columns were selected for numerical simulation. The height of the specimen section was 1000 mm, while the dimensions of the boundary column and wall web sections were 200 mm × 200 mm and 600 mm × 100 mm, respectively, (Fig.5). C80 concrete was used as the high-strength concrete. Table 1 shows the basic parameters of the specimen as well as the strength of reinforced concrete. The diameter of the stirrups in all specimens was 5 mm. The spacing between the stirrups of DHPCW-01 and DHPCW-03 was 30 mm and between those of DHPCW-02 and DHPCW-04 was 40 mm. The ultimate tensile strength of stirrup was 737.5 MPa. Table 2 shows the mechanical properties of the reinforcement bars obtained from the test.



(a) Elevation view (b) Elevation view 2-2



(c) Elevation view 2-2 of DHPCW-01and 03



(d) Elevation view 2-2 of DHPCW-02 and 04

Figure 5. Geometry and reinforcement of specimens (mm)

Table 1. Parameters of the specimen

Specimen number	H/mm	Height to width ratio	Cube compressive strength /Mpa	Axial compression ratio
DHPCW-01	2200	2.1	94.22	0.28
DHPCW-02	2200	2.1	96.89	0.21
DHPCW-03	1600	1.5	99.56	0.21
DHPCW-04	1600	1.5	89.33	0.21

Table 2. Mechanical properties of rebars

Reinforcement type	f_Y (N/mm^2)	f_U (N/mm^2)
Φ25	485.1	654.3
Φ16	452.9	614.6
Φ12	460.0	667.9
Φ10	494.0	575.2
Φ8	474.2	579.0
Φ6.5	419.3	550.3

Horizontal loads were applied by reciprocating actuators and the horizontal loading point was located in the center of the loading beam at the top of the wall. Figure 6 shows the loading device, in which the vertical load was provided by vertical hydraulic jack. A horizontal load was applied by an electro-hydraulic servo actuator. The cyclic horizontal load is controlled by a mixture of force and drift. Cracks occurred at the bottom of all boundary columns of all specimens. As the load increased, the cracks in the boundary columns extended to the wallboard and developed to the upper part of the specimens. Finally, the concrete at the bottom of the boundary columns and webs was crushed, and the longitudinal reinforcement was folded and exposed. Bending failure occurred in specimens DHPCW-01 and DHPCW-02, and shear failure occurred in specimens DHPCW-03 and DHPCW-04. Figure 7 shows the failure mode and crack distribution in each specimen.

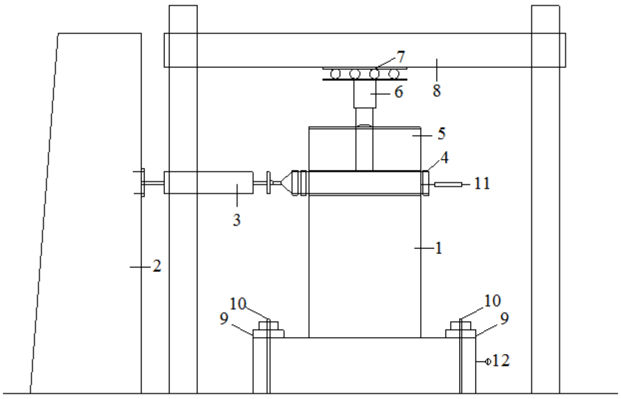
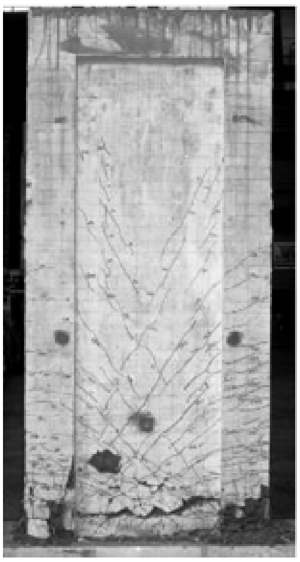
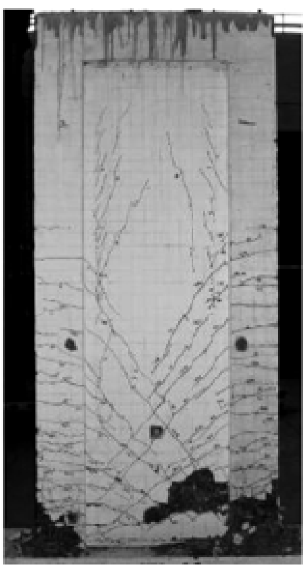


Figure 6. Test setup

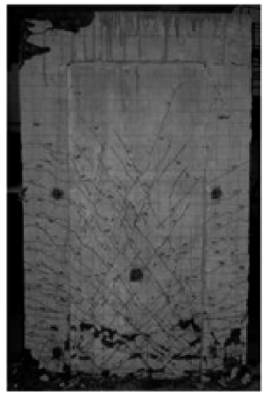
Notes: 1.speciment 2.reaction wall 3.actuator 4. horizontal connection 5. Rigid beam 6.jack 7. sliding support 8.reaction frame 9.pressure beam 10.anchor bolt 11.displacement meter 12.dialgage



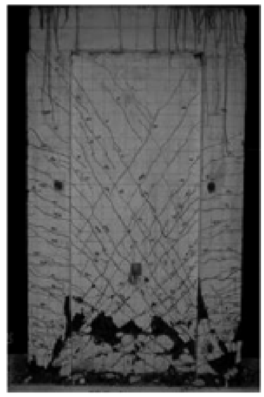
(a) DHPCW-01



(b) DHPCW-02



(c) DHPCW-03



(d) DHPCW-04

Figure 7. The failure mode and crack distribution in specimens

3.2 Comparison between Calculation and Experimental Results

According to the above calculation method, the boundary column and the wall web were divided into 1 and 5 fiber sections, respectively, while the wall was vertically divided into 4 units. According to *Code for design of concrete structures* [7], the conversion relationship between the cube compressive strength f_{cu} and the axial compressive strength f_c is given as follows:

$$f_c = 0.88\alpha_{c1}\alpha_{c2} f_{\mathrm{cu}} \tag{1}$$

where α_{c1} is the ratio of prism strength and cube strength and α_{c2} is the brittleness reduction factor, which was assumed to be 0.82 and 0.87, respectively, for the C80 concrete. The axial compressive strength of the concrete in each specimen can be obtained according to Equation 1.

The parameters obtained from the concrete compression constitutive curve are as follows: $\sigma_U = \mathrm{f_c}$, $\varepsilon_U = 0.0016$, $\varepsilon_L = 0.0021$, $\varepsilon_R = 0.0045$, $\varepsilon_X = 0.01$, $\sigma_Y = 39.8$MPa, and $\sigma_R/\sigma_U = 0.2$. The elastic modulus of C80 concrete is 38000 MPa [7]. The ε_X value of the reinforcement is 0.1. The elas-

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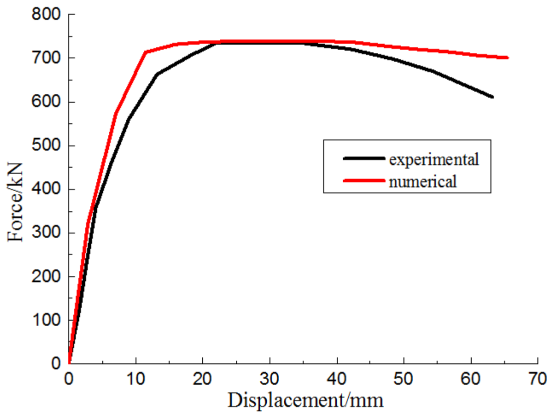
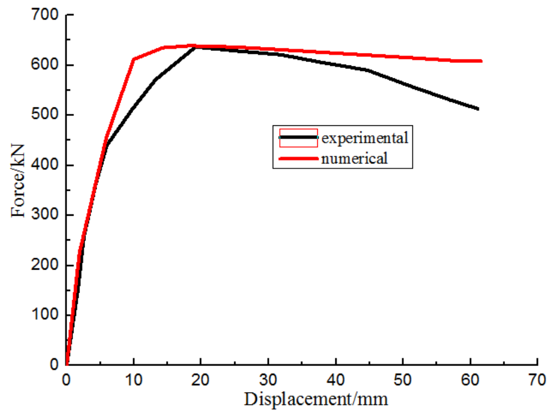
tic modulus of reinforcement is determined according to *Code for design of concrete structures* [7].

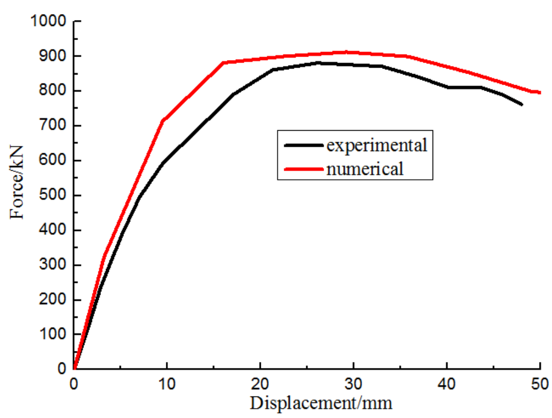
Push-over analysis was carried out on all specimens. Figure 8 illustrates a comparison between the analysis and the test values of each specimen. Figure 8 shows that the analysis curve was in good agreement with the test curve. In addition, the initial stiffness, yield load, peak load, and ultimate displacement of the specimen were accurately simulated. The results verified the feasibility and accuracy of the elasto-plastic analysis method for high-strength concrete shear wall with boundary column using the fiber model



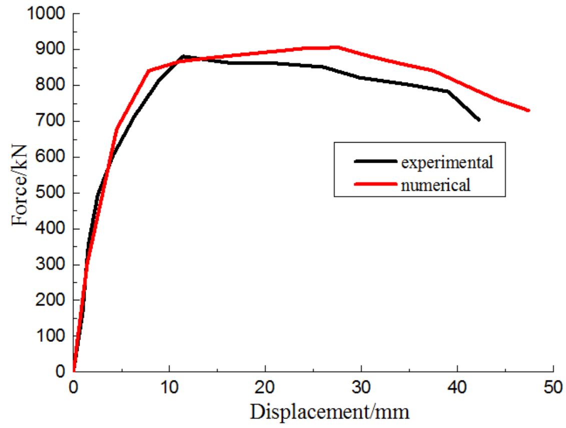
(a) DHPCW-01



(b) DHPCW-02



(c) DHPCW-03



(d) DHPCW-04

Figure 8. Comparison between the experimental and analysis results using skeleton curves

3.3 Parameter Analysis

In order to further study the seismic performance of high-strength concrete shear walls with boundary columns, the axial compression ratio, height to width ratio, ratio of vertical reinforcement, and ratio of longitudinal reinforcement in the boundary columns were selected for push-over analysis of high-strength concrete shear walls with boundary columns. The values of the parameters that were not set as variables in the analysis were set as the values obtained from DHPCW-02.

(1) Axial compression ratio

Figure 9 and Table 3 show the analysis results at different axial compression ratios (from 0.1 to 0.6). The yield displacement was calculated using the equal energy method [9]. The ultimate displacement was found to be the displacement corresponding to the peak load when it drops to 85% [10]. With the increase in the axial compression ratio, the bearing capacity first increased and then decreased, and the ultimate displacement showed a decreasing trend. At an axial compression ratio of 0.5, the bearing capacity reached 943.40 kN, which is 85.9 % higher than that obtained at an axial compression ratio of 0.1. However, the displacement ductility coefficient decreased from 6.45 to 4.99. At an axial compression ratio of 0.6, the bearing capacity slightly decreased at an axial compression ratio of 0.5. In addition, the ultimate displacement decreased to 16.62 mm, and the displacement ductility coefficient dropped to 1.82. Therefore, in order to ensure the seismic ductility of the shear wall with boundary columns, it was suggested that the axial compression ratio should not exceed 0.5.

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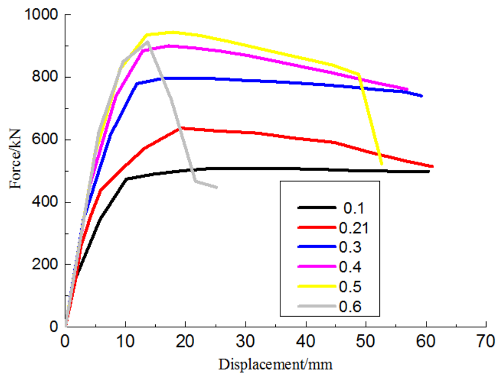

Figure 9. The effect of axial pressure ratio on the skeleton curve

Table 3. Test results under various axial compression ratios

axial compression ratio	bearing capacity	yield displacement	ultimate displacement	displacement ductility factor
0.1	507.37	9.36	60.42	6.45
0.21	648.92	9.69	61.06	6.30
0.3	796.88	9.54	59.21	6.21
0.4	899.42	9.95	56.12	5.64
0.5	943.40	9.80	48.91	4.99
0.6	912.51	9.13	16.62	1.82

(2) Height to width ratio

Figure 10 and Table 4 show the calculation results when the height to width ratio increased from 1.0 to 3.0. The increase in the height to width ratio causes the bearing capacity to decrease from 1291.21 kN to 485.07 kN, i.e., a 62.4% decrease. However, the ultimate displacement increased from 17.33 mm to 88.5 mm, and the ductility of displacement also gradually increased. The ductility coefficient of displacement increased from 3.85 to 6.67, i.e., it increased 1.73 times. These results show that the high-strength concrete shear wall with boundary columns exhibited good ductility with both low shear walls with a height to width ratio of 1.0 and high shear walls with a height to width ratio of 3.0.

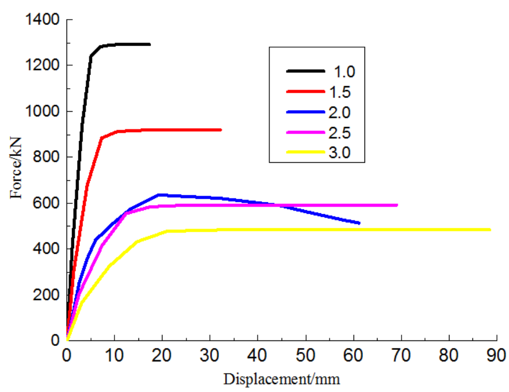

Figure 10. The influence of height to width ratio on skeleton curve

Table 4. The result for various height to width ratios

height to width ratio	bearing capacity	yield displacement	ultimate displacement	displacement ductility factor
1.0	1291.21	4.49	17.33	3.85
1.5	917.84	6.04	32.04	5.30
2.0	648.92	9.69	61.06	6.30
2.5	592.84	11.09	68.99	6.22
3.0	485.07	13.27	88.50	6.67

(3) Ratio of vertical reinforcement

Figure 11 and Table 5 show the effect of the ratio of vertical reinforcement on the high-strength concrete shear wall with boundary columns. When the ratio of vertical reinforcement increased from 0.55% to 1.31%, the bearing capacity increased only by 8.5%, and the ultimate displacement and displacement ductility coefficients remained almost unchanged. Therefore, the high-strength concrete shear wall with boundary columns do not require large number of vertically distributed rebars.

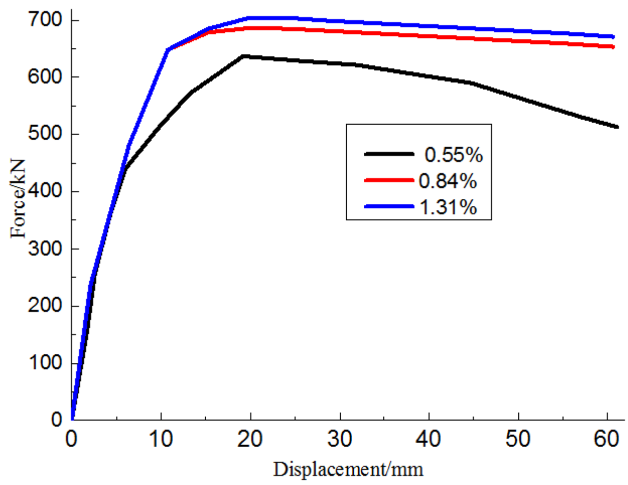

Figure 11. The effect of the vertical reinforcement ratio on skeleton curve

Table 5. The results of various ratios of vertically distributed reinforcements

ratio of vertical reinforcement	bearing capacity	yield displacement	ultimate displacement	displacement ductility factor
0.55%	648.92	9.69	61.06	6.30
0.84%	686.07	9.52	60.70	6.37
1.31%	704.07	10.09	60.65	6.02

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(4) The ratio of longitudinal reinforcement in boundary columns

Figure 12 and Table 6 show the calculation results when the ratio of longitudinal reinforcement in boundary columns increased from 1.16% to 4.62%. This increase was accompanied with an increase in the bearing capacity from 507.23 kN to 711.45 kN, i.e., a 40.3% increase. The limit displacement slowly increased, while the ductility coefficient of displacement decreased at first and then slowly increased, because the yield displacement increased at first and then decreased. The displacement ductility coefficients were all greater than 6. Therefore, the ratio of longitudinal reinforcement in boundary columns had a significant impact on the bearing capacity, and increasing it could improve the bearing capacity of high-strength concrete shear wall with boundary columns.

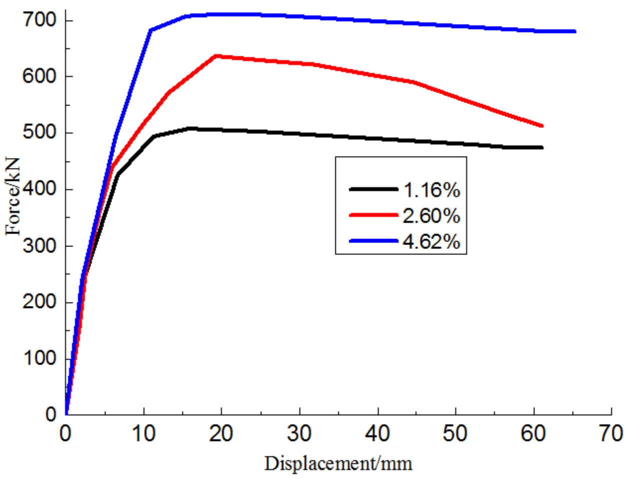

Figure 12. The effect of the ratio of longitudinal reinforcement in boundary columns on the skeleton curve

Table 6. Test results for various ratios of longitudinal reinforcement in the boundary columns

ratio of longitudinal reinforcement	bearing capacity	yield displacement	ultimate displacement	displacement ductility factor
1.16%	507.23	7.46	61.03	8.17
2.60%	648.92	9.69	61.06	6.30
4.62%	711.45	9.46	65.21	6.89

4. Conclusions

(1) The analysis results of the load-displacement curve were found to be close to the experimental results. The initial stiffness, yield load, peak load, and ultimate displacement of the specimen were found to be accurately simulated. Thus, the analysis method proposed here is able to accurately predict the bearing capacity, displacement, and ductility of high-strength concrete shear wall with boundary columns.

(2) The axial compression ratio was found to have a great impact on the bearing capacity and ductility of high-strength concrete shear walls with boundary columns. When the axial compression ratio increased from 0.1 to 0.6, the bearing capacity first increased and then decreased, and the ratio reached 0.6, the bearing capacity began to decrease. However, the ductility decreased in all cases, and the displacement ductility coefficient experienced a sudden change at an axial compression ratio of 0.6.

(3) As the height to width ratio increased from 1 to 3, the bearing capacity decreased by 62.4%, and the displacement ductility coefficient increased from 3.85 to 6.67, i.e., an increase of 1.73 times.

(4) The ratio of vertical reinforcement was found to have a little effect on the seismic behavior of high-strength concrete shear wall with boundary columns. Therefore, this type of walls should not be equipped with too many vertical rebars. The ratio of longitudinal reinforcement in boundary columns was found to have a significant effect on the bearing capacity, while the ductility was found to decrease at first and then slowly increase.

Acknowledgments

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References

[1] Xingwen Liang, Penghui Yang, Xiaoling Cui, Mingke Deng, Xinghu Zhang. Experimental studies on seismic behavior of high strength concrete shear wall with boundary columns[J]. Journal of Building Structures, 2010, 31(1): 23-32.

[2] Fanglong He, Yapeng Zhu. A 3d model in nonlinear analysis of reinforced concrete shear wall with side column[J]. Engineering Mechanics, 2008, 25(6): 124-129.

[3] Graham H Powell. A state of the art educational event performance based design using nonlineal analysis[R]. Computers and Structures, Inc., 2007.

[4] Computers and Structures, Inc. Nonlinear anaysis and performance assessment for 3D structures user guide[M]. Berkeley, California, USA: Computers and Structures, Inc., 2006

 DOI: https://doi.org/10.30564/jcr.v2i1.2694

[5] FEMA 356. Prestandard and commentary for the seismic rehabilitation of buildings[S]. Federal Emergency Management Agency:Washington, DC, 2000.
[6] Mander J B, Priestley M J N, Park R. Theoretical stress-strain model for confined concrete[J].Journal of structural engineering, 1988, 114(8): 1804-1826.
[7] GB 50010-2010 Code for design of concrete structures[S]. Beijing: China Communication Press, 2011: 63-64.
[8] Baolin Qin. Preliminary Evaluation on the Seismic Behavior of Super High-rise Structure Examples on the Support of PERFORM 3D Software[D].Chongqing: Chongqing University, 2012.
[9] Xiaolong Tong, Zhi Fang, Xiao Luo. Experimental study on seismic behavior of Reactive Powder Concrete shear walls[J]. Journal of Building Structures, 2016, 37(1): 21-30.
[10] Xiaowei Cheng, Xiaodong Ji, Richard S. Henry, Mengchao Xu. Coupled Axial Tension-Flexure Behavior of Slender Reinforced Concrete Walls[J]. Engineering Structures, 2019, 188: 261-276.

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ARTICLE

Inter-Organizational Conflict (IOC) in Building Refurbishment Projects; an Exploratory Factor Analysis (EFA) approach

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ABSTRACT

Over the past years, there has been an expanding intrigued in building refurbishment projects because of the alter in financial conditions and the accentuation on sustainable development. Increasing demand for building refurbishment projects will lead to an increase in organizational interactions in the construction works as building refurbishment works involve interactions among many different organizations and it can cause Inter-Organizational conflict (IOC) among organizations involved in projects. This paper adopted an Exploratory Factor Analysis (EFA) approach to analyses IOC in building refurbishment projects. For this study, a five-point Likert Scale was adopted to ensure the instruments of the study are reliable. The researcher ultimately sent questionnaires as a web-link and email invitation to 1050 construction firms and 733 architectural firms. The questionnaire sent to managers and professionals from construction and architectural firms in Malaysia. Finally, one-hundred-seventy-nine (179) refurbishment projects formed a database for this paper. The finding of this paper shows the IOC factors that contribute to the improve the performance of building refurbishment project can be conflict during the construction stage, conflict between the client and the consultant, task expectations, basic responsibilities, final duration, project's goals, conflict between the client and the contractor, final cost, final quality, standards of behaviors, conflict between the contractor and the consultant, interference and conflict during the design stage.

1. Introduction

Over the past years, there has been an expanding intrigued in building refurbishment projects because of the alter in financial conditions and the accentuation on sustainable development [41]. Investment for new construction projects would likely decrease, but the need for building refurbishment works would likely increase. This is since the demand for building refurbishment projects comes from various sources such as obsolescence and deterioration. In spite of the financial downturn, building proprietors still ought to repair their property [13]. Building/house refurbishment is defined as works that involve renovation, upgrading, retrofit, improvement, and repair of existing and occupied buildings [22, 46]. Besides, the demands for building refurbishment works are likely to increase in the next decade due to the regeneration of inner cities and towns, and growing concerns about building on greenfield sites. Thus, renovation and refurbishment of existing buildings plays a considerable role in attaining sustainable

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environment in the urban area [63].

Depending on the nature and size of the project, a building refurbishment project involves many organizations, which may include client, consultants, and contractor [59, 61]. The involvement of many organizations with different objectives and orientations tends to cause IOC [71]. In construction projects, an understanding of conflict is more important now than ever before given the differentiation that exists in today's project organizations in which the inter-organizational integration within a project can be difficult [23, 39, 56]. However, comparatively little research has been done on inter-organizational conflicts in building refurbishment. This means that there is a gap of knowledge and lack of research in renovation and refurbishment projects. This gives the impetus to conduct this study. Hence, the objective of this research is to evaluate the level of IOC in refurbishment projects through an Exploratory Factor Analysis (EFA) approach.

2. Literature Review

Inter-Organizational Conflicts (IOCs) in construction projects are inevitable and unavoidable because organizations involved in the projects have different norms, background, skills, and knowledge [16]. The organizations are working temporarily together as a team and making decisions to meet project goals and objectives [45]. Conflicts can be destructive, affecting the projects' performance [36, 42]. Deutsch (1973) defined destructive conflict as a satiation, in which people and organizations are unsatisfied with the performance outcome. However, conflicts need not be destructive [7,73]. In fact, conflicts can be constructive. In some cases, conflicts can be beneficial because without conflict, organizations and people are likely to become stagnant, apathetic, non-innovative, and unable to respond to change. However, it could be argued that when the projects are uncertain, the duration is short, and the activities are intense, which are typical of refurbishment projects in which the level of conflicts should be kept to a minimum. The organizations do not have time to know and accommodate each other. The outcome of the conflict is more likely to be destructive than constructive.

To reduce conflicts, organizations involved in building refurbishment projects need to reduce the level of uncertainty. In uncertainty, when organizations have different perceptions and interpretation of the problems, IOCs are more likely to occur because organizations are not able to agree [50,57]. Moreover, when conflicts are frequent, it has significant economic and social consequences [45]. Literature review also reveals that there are numerous effects of IOC in construction projects which include final cost, final duration [72], final quality [51], interface, and task expectation [11].

Construction projects, which include refurbishment projects typically start well, but problems can lead to conflicts between the client and contractor [72]. Moreover, [16] mention that in construction projects, conflicts sometimes seem inevitable due to high differences in interests among the contractors and clients. Conflict is common between clients and consultants because they almost always disagree over some issues such as cost estimation, structural design, and architectural design, when they start working together [24].

From the above literature, it could be concluded that disagreement over their basic responsibilities, disagreement on how to achieve the project's goals, disagreement over task expectations, disagreement agreed over the interference of other project members in their works, disagreement over standards of behaviors, the client and the contractor, disagreement on the final cost, the client and the contractor disagreement on the final duration, the client and the contractor disagreement on the final quality, the level of organizational conflict between the client and the contractor in the building refurbishment project is low, the level of organizational conflict between the client and the consultants in the building refurbishment project is low, the level of organizational conflict between the contractor and the consultants in the building refurbishment project is low, the level of IOC during the design stage in the building refurbishment project overall is low, and the level of IOC during the construction stage in the building refurbishment project overall is low, are factors that contribute to the inter-organizational conflict in building refurbishment projects during both the design and construction stage among organizations involved in building refurbishment projects. The factors that contribute to IOC in building refurbishment projects are shown in Table 1:

Table 1. The factors that cause conflict in building refurbishment projects

Inter-Organizational Conflict Factors	Authors
Disagreement Over Their Basic Responsibilities.	(Narh et al., 2015; Schultz & Schultz, 2010; Sousa & Camelo, 2014; Vaaland & Håkansson, 2003; Verma, 1998)
Disagreement on How to Achieve the Project's Goals.	(Ali et al., 2013; Harmon, 2003; Kerzner, 2013; Senaratne et al., 2013; Wilmot & Hocker, 2010)
Disagreement Over Task Expectations.	(Diekmann & Girard, 1995; Gould, 2004; Molenaar et al., 2000; Goldman, 2002; Vaux & Kirk, 2014)
Disagreement Over the Interference of Other Project's Members in Their Works.	(Barki & Hartwick, 2001; Bekele, 2015; Deutsch, 1973; Moura & Teixeira, 2010; Sambasivan & Soon, 2007)
Disagreement Over Ethical Standards of Behaviours.	(Jefferies et al., 2003; Kang, 2004; Lumineau et al., 2015)

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Inter-Organizational Conflict Factors	Authors
Disagreement Over the Final Cost	(Cakmak & Cakmak, 2013; S. O. Cheung & Pang, 2013; Jr & Polkinghorn, 2008; Khahro & Ali, 2014; Xiang et al., 2012)
Disagreement Over the Final Duration	(Ashworth, 2013; Bachmann et al., 2012; Cakmak & Cakmak, 2013; Ilter, 2012; Khahro & Ali, 2014; Waddell et al., 2013)
Disagreement Over the Final Quality	(Bekele, 2015; Cakmak & Cakmak, 2013; Cheung & Pang, 2013; Jha, 2013; Yang et al., 2009)
Organizational Conflict Between the Client and The Contractor	(Acharya et al., 2006; Mitkus & Mitkus, 2014; Spang & Riemann, 2011; Vaux & Kirk, 2014; Yates, 2003)
Organizational Conflict Between the Client and The Consultants	(Aziz & Abdel-Hakam, 2016; Bekele, 2015; Golembiewski, 2000; Halac et al., 2013; Lindhard et al., 2016; Nikolova et al., 2014)
Organizational Conflict Between the Contractor and The Consultants	(Arain, 2005; Bekele, 2015; Mitkus & Mitkus, 2014)
Inter-Organizational Conflict During the Design Stage	(Grebici et al., 2006; Mark Klein, 2000; Msallam et al., 2015; Senaratne et al., 2013)
Inter-Organizational Conflict During the Construction Stage	(Jackson, 2010; Liu, 2014; Sousa-ginel & Camelo-ordaz, 2014)

3. Methodologies

To achieve the research objective, two steps of data collection were employed in this study. The phases are the literature review and questionnaire survey. The first stage begun with the study of secondary data collected through vast and extensive literature reviews. The literature review for this study was done through reading and exploring in project management, general management, refurbishment published in referred journals, conferences, and textbooks. The literature review section explains the IOC in the construction and refurbishment and renovation projects. The research problems and variables were identified from literature review as the literature survey helps to make a precise and clear problem statement [66]. The second phase of this research involves the questionnaire survey. The data was collected from boundary role persons in construction and architectural firms that have experience in refurbishment and renovation projects to evaluate the information needed regarding refurbishment projects in Malaysia. The questionnaires were formed from literature reviews. According to [17] researchers have three ways to design and develop questionnaires, modify an existing one, or using one that they have located in literature. Therefore, this research developed its own questionnaire following the structure from previous re-searches done by [3,55,59].

However, in many different ways the structured questionnaire data can be collected, containing Web-Based Survey, email, direct mailing, drop-off and pick-up, telephone interviews, and face-to-face interviews [Antwi & Hamza, 2015; Ticehurst & Veal, 2000]. Therefore, for this study Web-Based Survey is employed to collect the data from respondents. The Web-Based questionnaire is the latest tool and is becoming one of the most used method to of collect questionnaire data. To host this research the Survey Monkey program was chosen because this program is easy to use, economical and it met the needs of the researcher. Therefore, this study over-comes multiple replies, and confidential issues by: first, monitoring the access of respondents by letting only users with a unique IP address to complete the survey; and second, delivering obvious written steps on how respondents' confidentiality is treated and how the data is transmitted in this research. For this research, the data was collected from boundary role persons in contractor and architectural firms regarding refurbishment projects in Malaysia. Web-Based questionnaires survey helped to gather data in a short period and questionnaires have been sent swiftly to numerous kinds of respondents and all selected samples had an impartial chance to respond. In this study, a self-administered questionnaire with close-ended questionnaire was employed. Moreover, Likert's Scale was used as the rating method for this study. Likert items are used to measure the respondents' attitudes to a particular question or statement. In current studies, most Likert's Scales, contain either five to seven-point scales categories [66,80]. Thus, for this study, a five-point Likert Scale was adopted as 1 = Totally Disagree; 2 = Disagree; 3 = Moderate (Neither Agree nor Disagree); 4 = Agree; 5 = Totally Agree, to ensure the instruments of the study are reliable. The researcher ultimately sent questionnaires as a web-link and email invitation to 1050 construction firms and 733 architectural firms. The respondents were asked to complete the questionnaires within a week. The author sent a reminder every week for five weeks to all respondents who did not respond to the questionnaire. Researchers have widely accepted the use of follow-up techniques as having significant effects in improving response rate [21,53]. After five weeks, the author received 302 responses from the project managers, site engineers, site directors, and site supervisors of the construction firms and 178 responses from principal architects and architects of the architectural firms. The overall response rate for construction firms was 28 percent and the valid response rate was 10 percent. For architectural firms, the total response rate was 25 percent, and the valid response rate was 12 percent. Finally, the overall response rate for both construction and architectural firms is 27 percent and the valid response rate is 11 percent. All 188 respondents were registered with the Construction Industry Development Board (CIDB) and Malaysian Institute of

Architect (PAM). In this research to validate and refine the data collected, the Exploratory Factor Analysis (EFA) was used. The Statistical Package for Social Science (SPSS) was used in both descriptive and inferential statistics. EFA usually applied to regroup variables into a limited set of clusters based on shared variance. Therefore, EFA aids to isolate concepts and constructs [18].

4. Findings and Discussion

Factor Analysis (FA) is a statistical method employed to classify a moderately small number of variables, which can be applied to show the relationship among sets of many interrelated variables [58]. Moreover, FA takes a large set of variables and looks for a way the data may be lessened or summarized applying a smaller set of variables [37].

In this study, to verify that data set is suitable for EFA, Bartlett's Test of Sphericity (BTS) and Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO) are used. The value of KMO is >0.6, and the significant value of BTS is <0.05 [57]. Table 2 shows that the amount of KMO is more than 0.6, which is an acceptable KMO value. Thus, the BTS is significant, so the data meets this assumption, and the values are appropriate for EFA.

Table 2. Initial assumptions of EFA

	KMO	BTS		
		Approx. Chi-Square	Df	Sig
IOC	0.953	2874.404	78	0.000

Note: BTS = Bartlett's Test of Sphericity; KMO = Kaiser-Meyer-Olkin; IOC=Inter-Organizational Conflict.

Table 3 shows the EFA analysis for Analysis for IOC by applying the CP derivation technique with a combination of the Varimax Rotation method. The Kaiser-Meyer-Olkin measure of sampling adequacy indicates that the strength of the relationships among variables is high (KMO = 0.953). Likewise, Bartlett's Test of Sphericity (BTS) for inter-organizational conflict items is significant where the significance value of BTS is <0.05 (X2 (78) = 2874.404, P<.001). Therefore, it can be concluded that the values are appropriate for EFA. Table 4.10 shows that one variable should be extracted from inter-organizational conflict since one Eigenvalue is exceeded (Eigenvalue = 9.69). This extracted variable is predicted to have 74.51% of the Variance Explained to explain the inter-organizational conflict variables. The group items are called inter-organizational conflict (Cronbach's alpha = 0.971). It shows that the grouped item has a good reliability value since Cronbach's alpha value is above 0.80, where the acceptable value is > 0.70.

Table 3. Summary results of EFA analysis for inter-organizational conflict

Factors and Items Included		Code	Factor Loading	Communalities
Inter-Organizational Conflict (IOC)	Conflict During the Construction Stage	Q313	.912	.827
	Conflict Between the Client and the Consultant	Q310	.907	.817
	Task Expectations	Q33	.893	.790
	Basic Responsibilities	Q31	.889	.789
	Final Duration	Q37	.886	.813
	Project's Goals	Q32	.877	.828
	Conflict Between the Client and the Contractor	Q39	.876	.825
	Final Cost	Q36	.858	.793
	Final Quality	Q38	.849	.746
	Standards of Behaviors	Q35	.847	.746
	Conflict Between the Contractor and the Consultant	Q311	.823	.770
	Interference	Q34	.812	.763
	Conflict During the Design Stage	Q312	.784	.747
Eigenvalue = 9.687, % Variance Explained = 74.51%, Cronbach's alpha = .971				

Note: index = .953; BTS, X2 (78) = 2874.404, P<.001

Based on Exploratory Factor Analysis (EFA), it could be concluded that the main factors, which contribute to the inter-organizational conflicts in refurbishment projects are: conflict during the construction stage, conflict between the client and the consultant, task expectations, basic responsibilities, final duration, project's goals, conflict between the client and the contractor, final cost, final quality, standards of behaviors, conflict between the contractor and the consultant, interference and conflict during the design stage.

5. Conclusion

This study reveals that the managing and controlling inter-organizational conflicts of refurbishment and renovation projects have not been addressed appropriately in earlier studies. Surveys on practices applied to the management of this uncertain environment are scarce and have lacked a theoretical underpinning. However, the construction projects are facing major problems when they come to completing projects. This is especially the case for refurbishment projects. Mostly in refurbishment projects the performance is not satisfactory, and many valuable resources have been wasted because of failed projects. The first reason for these problems is rooted in a high level of uncertainty, which is an integral part of refurbishment

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projects. The second reason is an inter-organizational conflict due to the presence of different organizations in projects.

The finding of this paper shows that inter-organizational conflicts (IOCs) can be significantly reduced if project managers are able to control the IOC factors in refurbishment projects. The IOC factors include conflict during the construction stage, conflict between the client and the consultant, task expectations, basic responsibilities, final duration, project's goals, conflict between the client and the contractor, final cost, final quality, standards of behaviors, conflict between the contractor and the consultant, interference and conflict during the design stage. As a result, by controlling IOC factors, the level of uncertainty will be practically reduced, and it helps to achieve a better performance. The findings of this paper would help construction and refurbishment projects managers to control, monitor and reduce inter-organizational conflicts among organizations involved a project.

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References

[1] Acharya, N. K., Lee, Y. D., Kim, J. K. Critical construction conflicting factors identification using analytical hierarchy process. KSCE Journal of Civil Engineering, 2006, 10(3): 165-174.
DOI: https://doi.org/10.1007/BF02824057

[2] Ali, A. A., Au-Yong, C., Au-Yong, C. The designer in refurbishment projects: implications to the compatibility of design. Structural Survey, 2013, 31(3): 202-213.
DOI: https://doi.org/10.1108/SS-11-2012-0038

[3] Ali, A. S., Rahmat, I. Methods of coordination in managing the design process of refurbishment projects. Journal of Building Appraisal, 2009, 5(1): 87-98.

[4] Antwi, S. K., Hamza, K. Qualitative and Quantitative Research Paradigms in Business Research: A Philosophical Reflection. European Journal of Business and Management, 2015, 7(3): 217-225.

[5] Arain, F. Potential Barriers in Management of Refurbishment Projects. Journal of Independent Studies and Research, 2005, 3(1): 22-31.

[6] Ashworth, A. Contractual procedures in the construction industry, sixth edition. In Contractual Procedures in the Construction Industry, Sixth Edition. Pearson/Prentice, Hall, 2013.
DOI: https://doi.org/10.4324/9781315847061

[7] Assael, H. Constructive Role of Interorganizational Conflict. Administrative Science Quarterly, 1962, 14(4): 573-583.
DOI: https://doi.org/10.2307/2391595

[8] Aziz, R. F., Abdel-Hakam, A. A. Exploring delay causes of road construction projects in Egypt. Alexandria Engineering Journal, 2016, 55(2): 1515-1539.
DOI: https://doi.org/10.1016/j.aej.2016.03.006

[9] Bachmann, R., Blois, K. K. J., Ivens, B. B. S., candace jones, Lichtenstein, benyamin b., Chan, A., Ho, D. D., Tam, C., Fong, P. P. S., Lung, B. W. B., Goethals, F. G., Ho, D. D., Hsu, M.-H., Ju, T. L., Yen, C.-H., Chang, C.-M., Blois, K. K. J., Ivens, B. B. S., Laan, A., … Cheung, S. O. Interorganizational Teamwork in the Construction Industry. Administrative Science Quarterly, 2012, 133(February), 157-168.
DOI: https://doi.org/10.1061/(ASCE)0733-9364(2007)133:2(157)

[10] Barki, H., Hartwick, J. Interpersonal Conflict and Its Management in Informastion System Development. MIS Quarterly, 2011, 25(2):195-228.
DOI: https://doi.org/10.2307/3250929

[11] Bekele, A. Alternative Dispute Resolution Methods in Construction Industry : an Assesment of Ethiopian Situation. A Thesis Submitted To the School of Graduate Studies Addis Ababa University Faculty of Technology, 2015: 1-147.

[12] Cakmak, P., Cakmak, E. An Analysis of Causes of Disputes in the Construction Industry Using Analytical Hierarchy Process (AHP). Ascelibrary. Org, 2013:94-102.
DOI: https://doi.org/10.1061/9780784412909.010

[13] Chan, A. P. C., Hon, C. K. H. Safety of repair, maintenance, minor alteration, and addition (RMAA) works : a new focus of construction safety. Routledge, 2016.

[14] Cheung, S. O., Pang, K. H. Y. Anatomy of Construction Disputes. Construction engineering and management, 2013, 139(January), 15-23.
DOI: https://doi.org/10.1061/(ASCE)CO.1943-7862.0000532

[15] Cheung, S. O., Yiu, T. W. Are Construction Disputes Inevitable. IEEE Transactions on Engineering Management, 2006, 53(3): 456-470.
DOI: https://doi.org/10.1109/TEM.2006.877445

[16] Cheung, S., Yiu, K., Chim, P. How relational are construction contracts? Journal of Professional Issues in …, 2006, January, 48-56.

[17] Creswell. The Selection of Research Design Chapter, 2009: 3-22.

[18] David J. Malaysia social media statistics 2014. In Malaysia Asia, 2015.

[19] Deutsch, M. The Resolution of Conflict: Constructive and Destructive Processes. In American Behavioral Scientist, 1973, 17(2):248. Yale University Press. DOI: https://doi.org/10.1177/000276427301700206

[20] Diekmann, J. E., Girard, M. J. Are Contract Disputes Predictable? Journal of Construction Engineering and Management, 1995, 121(December), 355-363. DOI: https://doi.org/10.1061/(ASCE)0733-9364(1995)121:4(355)

[21] Edwards, P. J., Roberts, I., Clarke, M. J., Diguiseppi, C., Wentz, R., Kwan, I., Cooper, R., Felix, L. M., Pratap, S. Methods to increase response to postal and electronic questionnaires. The Cochrane Database of Systematic Reviews, 2009, 3, MR000008. DOI: https://doi.org/10.1002/14651858.MR000008.pub4

[22] Egbu, C. Management education and training for construction work within the construction industry, 1994.

[23] Gardiner, P. D., Simmons, J. E. L. Case explorations in construction conflict management. Construction Management and Economics, 1995, 13(3): 219-234. DOI: https://doi.org/10.1080/01446199500000026

[24] Golembiewski, R. T. Handbook of organizational consultation. Marcel Dekker, 2000.

[25] Gould, N. Dispute resolution in the construction industry : An overview. Construction Law, September, 2004:1-34.

[26] Grebici, K., Ouertani, M., Blanco, E. Conflict Management in Design Process : Focus on Changes Impact. 13th ISPE International Conference on Concurrent Engineering, 2006:1-8.

[27] Halac, M., Azoulay, P., Biais, B., Bolton, P., Dessein, W., Gibbons, B., Hagiu, A., Kartik, N., K″ Oszegi, B., Macdonald, G., Ryall, M. Relationship Building: Conflict and Project Choice over Time a, 2013.

[28] Harmon, K. M. J. Conflicts between Owner and Contractors: Proposed Intervention Process. Journal of Management in Engineering, 2003, 19(3): 121-125. DOI: https://doi.org/10.1061/(ASCE)0742-597X(2003)19:3(121)

[29] Hulthén, H. A model of contextual factors and inter-organizational integration: A Grounded Theory study of two supply chains, 2013: 1-228.

[30] Ilter, D. Identification of the relations between dispute factors and dispute categories in construction projects. International Journal of Law in the Built Environment, 2012, 4(1):45-59. DOI: https://doi.org/10.1108/17561451211211732

[31] Jackson, B. J. Construction Management JumpStart: The Best First Step Toward a Career in Construction Management. Sybex, 2010.

[32] Jefferies, M., Kirk, A., Hampson, A., Mccann, J. Ethical construction procurement. 2003: 254-266.

[33] Jha, K. N. Determinants of Construction Project Success in India. Springer Netherlands, 2013, 23. DOI: https://doi.org/10.1007/978-94-007-6256-5

[34] Jr, L. A., Polkinghorn, B. Managing conflict in construction megaprojects: Leadership and third-party principles. Conflict Resolution Quarterly, 2008, 26(2). DOI: https://doi.org/10.1002/crq

[35] Juan, Y.-K., Kim, J. H., Roper, K., Castro-Lacouture, D. GA-based decision support system for housing condition assessment and refurbishment strategies. Automation in Construction, 2009, 18(4): 394-401. DOI: https://doi.org/10.1016/j.autcon.2008.10.006

[36] Jukuri, K. Identity Projects of Design Professionals-Identity Construction Using Social Media. Aalto University School of Business, 2013.

[37] Julie Pallant. SPSS survival manual: a step by step guide to data analysis using IBM SPSS. In Australian & New Zealand Journal of Public Health (4th ed.). Allen & Unwin, 2013. DOI: https://doi.org/10.1046/j.1365-2648.2001.2027c.x

[38] Kang, B. Developing a Systems Approach for Managing Ethics in Construction Project Environments. ARCOM, 2004, 2(September), 1-9.

[39] Kerzner, H. H. R. Project management: a systems approach to planning, scheduling, and controlling. In New York, 2013. DOI: https://doi.org/10.1016/0377-2217(82)90164-3

[40] Khahro, S. H., Ali, T. H. Causes Leading To Conflicts in Construction Projects : A Viewpoint of Pakistani Construction Industry, 2014: 116-121.

[41] Kohler, N. and Hassler, U. Interdisciplinary architectural research: cultural heritage and resource conservation. Proceedings of the 2 nd Conference ARCC-AEEA, 2000, 4-7 July, Paris.

[42] Kumarasswamy, M. M. Conflicts, claims and disputes in construction. Engineering, Construction and Architectural Management, 1997, 4(2): 95-111. DOI: https://doi.org/10.1108/eb021042

[43] Lindhard, S. M., Shen, G. Q., Brunoe, T. D., Larsen, J. K. Factors Affecting Schedule Delay, Cost Overrun, and Quality Level in Public Construction Projects. Journal of Management in Engineering, 2016, 32(1), 4015032. DOI: https://doi.org/10.1061/(ASCE)ME.1943-

DOI: https://doi.org/10.30564/jcr.v2i1.2732

5479.0000391
[44] Liu, T. Conflicting Objectives in Interfaces of Construction Project (Issue June). Norwegian University of Science and Technology, 2014.
[45] Lumineau, F., Eckerd, S., Handley, S. Inter-organizational conflicts. Journal of Strategic Contracting and Negotiation, 2015, 1(1):42-64.
DOI: https://doi.org/10.1177/2055563614568493
[46] Mansfield, J. R. What's in a name? Complexities in the definition of "refurbishment." Property Management, 2002, 20(1):23-30.
DOI: https://doi.org/10.1108/02637470210418942
[47] Mark Klein. Computational conflicts : conflict modeling for distributed intelligent systems, with contributions by numerous experts. In Computational conflicts. Springer, 2000.
[48] Mitkus, S., Mitkus, T. Causes of Conflicts in a Construction Industry: A Communicational Approach. Procedia-Social and Behavioral Sciences, 2014, 110, 777-786.
DOI: https://doi.org/10.1016/j.sbspro.2013.12.922
[49] Molenaar, K., Washington, S., Diekmann, J. Structural Equation Model Of Construction Contract Dispute Potential. August, 2000: 268-277.
[50] Moura, Helder. Managing Stakeholders Conflicts. Construction Stakeholder Managemen, 1997: 286-316.
[51] Moura, HMP, Teixeira, J. Managing stakeholders conflicts. Construction Stakeholder Management, 2010: 286-316.
[52] Msallam, M., Abojaradeh, M., Jrew, B., Zaki, I. Controlling Of Variation Orders in Highway Projects in Jordan. Journal of Engineering and Architecture, 2015, 3(2): 95-104.
DOI: https://doi.org/10.15640/jea.v3n2a11
[53] Nakash, R. A., Hutton, J. L., Jørstad-Stein, E. C., Gates, S., Lamb, S. E. Maximising response to postal questionnaires--a systematic review of randomised trials in health research. BMC Medical Research Methodology, 2006, 6, 5.
DOI: https://doi.org/10.1186/1471-2288-6-5
[54] Narh, O. C., Owusu, E. E., Narh, T. J. An Exploratory Study of Professional Conflicts and Disputes within the Construction Industry, 2015, 3(12): 44-65.
[55] Nikolova, N., Möllering, G., Reihlen, M. Trust Building Practices in Client-Consultant Relationship, 2014.
[56] Noori, A., Mokariantabari, M. Inter-Organizational Integration (IOI) in Building Refurbishment Projects; an Exploratory Factor Analysis (EFA) Approach. International Journal of Scientific & Engineering Research, 2019a, 10(11): 1361-1366.
[57] Noori, A., Mokariantabari, M. Uncertainties in Building Refurbishment Projects; an Exploratory Factor Analysis (EFA) Approach. International Journal of Scientific & Engineering Research, 2019b, 10(11): 1065-1068.
[58] Norušis, M. J. (Marija J. SPSS Professional Statistics 6.1. SPSS Inc, 1994.
[59] Ntiyakunze, S. K. Conflicts in Building Projects in Tanzania : Analysis of Causes and Management Approaches. Royal Institute of Technology (KTH), Stockholm, Sweden, 2011.
[60] Nurulhudaya, A. H. The Standards Forms of Contract and the Contractual Behaviour on the Performance of Refurbishment Projects. Universiti Teknology MARA, 2012.
[61] Rahmat, I., Nordin, H., Ali, A. S. The complexity and performance of housing refurbishment projects/Ismail Rahmat, Hashimah Nordin and Azlan Shah Ali. In Built Environment Journal, 2005.
[62] Ralph Goldman. The Future Catches Up: Arms Control, Peacekeeping, Political Behavior. iUniverse, 2002.
[63] Riley, M., Cotgrave, A. Construction technology. Technology of refurbishment and maintenance. Palgrave Macmillan, 2011, 3.
[64] Sambasivan, M., Soon, Y. W. Causes and effects of delays in Malaysian construction industry. International Journal of Project Management, 2007, 25(5):517-526.
DOI: https://doi.org/10.1016/j.ijproman.2006.11.007
[65] Schultz, D. P., Schultz, S. E. Psychology and work today : an introduction to industrial and organizational psychology. Thomson/Wadsworth, 2010.
[66] Sekaran, U. Research method of business: A skill-building approach. In Writing. Wiley, 2006.
DOI: https://doi.org/http://www.slideshare.net/basheerahmad/research-methods-for-business-entire-ebook-by-uma-sekaran
[67] Senaratne, S., Udawatta, N., Gunasekara, D. Intragroup Conflicts In The Pre Contract Stage. Proceedings of the 38th Australasian Universities Building Education Association Conference, 2013:20-22, November 2013, Auckland, New Zealand.
[68] Sousa-ginel, C. C. J. G. E., Camelo-ordaz, C. Antecedents of relationship conflict in top management teams. International Journal of Conflict Management, 2014, 25(2):124-147.
DOI: https://doi.org/10.1108/IJCMA-06-2012-0054
[69] Spang, K., Riemann, S. A guideline for partnership between client and contractor in infrastructure projects in Germany. Management and Innovation for a Sustainable Built Environment, 2011, June, 20-21.

[70] Ticehurst, G. W., Veal, A. J. 2000 Business Research Methods-A Managerial Approach. Longman, 2000.
[71] Vaaland, T., Håkansson, H. Exploring interorganizational conflict in complex projects. Industrial Marketing Management, 2003, 32(2):127-138.
[72] Vaux, J. S., Kirk, W. M. Relationship conflict in construction management and how it affects performance and profit (Vol. 3684806), 2014.
[73] Verma, V. K. Conflict management. The Project Management Institute, d, 1998:1-12.
DOI: https://doi.org/10.1111/j.1365-2702.2010.03557.x
[74] Waddell, D., Jones, G., George, J. Contemporary Management. 2013:805.
[75] Williamson, O. E. Transaction-cost economics : The governance of contractual relations. Journal of Law and Economics, 1979, 22(2):233-261.
DOI: https://doi.org/10.1086/466942
[76] Wilmot, W. W., Hocker, J. L. Interpersonal conflict. McGraw-Hill, 2010.
[77] Xiang, P., Zhou, J., Zhou, X., Ye, K. Construction project risk management based on the view of asymmetric information. … Engineering and Management, November, 2012:1303-1311.
DOI: https://doi.org/10.1061/(ASCE)CO
[78] Yang, J., Shen, G. Q., Ho, M. F., Drew, D. S., Chan, A. P. C. Exploring Critical Success Factors for Stakeholder Management in Construction Projects. Journal of Civil Engineering and Management, 2009, 15(4):337-348.
DOI: https://doi.org/Doi 10.3846/1392-3730.2009.15.337-348
[79] Yates, D. Can claims and disputes (in construction contracts) be prevented or reduced? Building Journal Hongkong China, June, 2003.
[80] Zainudin, H. A. Research Methodology for Business & Social Scince (1st ed.). UiTM Publication Centre (UPENA), 2010.

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ARTICLE

Design and Development of a New Control System for Improving Energy Efficiency and Demand Response

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ABSTRACT

One of the best strategies for improving energy efficiency in any system is using the energy resources in the facilities properly. Using energy systems only when they are absolutely necessary is one of the best cost-benefit ratio strategies, i.e. the best energy saving strategy is, not using it. The aim of this paper resides on introducing a new Energy Management and Control System (EMCS), developed by the authors, which has been installed at the Universitat Politècnica de València. Alongside the paper, the architecture, the components and the installation cost analysis of the EMCS, as well as management actions implemented in the university and the obtained results are presented. Furthermore, this innovative system has been designed to improve demand response in energy systems by providing consumers with a tool for responding actively to energy demands, and also to provide all the different electrical market agents with a communication and business platform for exchanging information.

1. Introduction

Approximately one third of the primary energy supply is consumed in the residential sector, therefore it can be stated that buildings sector is one of the main energy consumers in the actual energy demand mix. In developing countries, buildings account for between 30 and 40% of the total energy consumed [1], a trend that is increasing in energy consumption as well as in carbon dioxide emissions.

Consequently, buildings are primary contributors to global warming, greenhouse gas emissions and ozone depletion.

In order to prevent the global warming effect, and thereby keeping the effects of climate change within acceptable limits, the atmosphere CO_2-equivalent concentrations should be stabilized and CO_2 emissions should be reduced [2]. Considering that the building sector is a significant energy consumer segment due to both, the energy demand required and the long useful lifespan of buildings, anticipated important energy savings may come about if building energy demand is minimized.

Hence, achieving better energy efficiency in buildings has become one of the world's major challenges. As heating, ventilation and air-conditioning (HVAC) and lighting account for the major part of a building's energy use, it is vital to understand a building´s energy trends and its energy systems´ operation in order to optimize their overall

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energy performance [3].

In general, most of the required energy in buildings is used to maintain acceptable comfort levels. In this regard, lighting and HVAC systems are the largest consumption systems, as it is stated in several studies which indicate that air-conditioning is responsible for between 10 and 60% of the total building energy consumption, depending on the building type [4-7]. This clearly indicates that HVAC equipment is a key system for tackling energy efficiency since it has a large energy savings potential. Furthermore, it is also necessary to consider the implementation of an energy management tool as a cost-effective measure to improve energy efficiency in HVAC systems, without compromising the user`s comfort. Thus, in analyzing the energy behavior in buildings, not only should a good construction design be considered, but also analysis of the correct use of the different facilities in order to demand the minimum energy just when the user requires it.

It is common to find HVAC management control systems in large size buildings, although during the years, these systems have also extended their functioning to the control of lighting-switch circuits and facilities access. There are many commercial brands, such as Honeywell, Siemens, Johnson controls, etc., that provide these equipment [8-10].

The energy management and control system (EMCS) presented in this article have many characteristics in common with other building management systems (BMS), since they are frequent technological solutions based on distributed intelligent processors, each one of them with its own autonomy, but altogether working in concert exchanging data at any moment required.

The application programs dedicated to control the energy systems are located within each distributed intelligent processor. These application programs carry out functions of monitoring, automation, regulation (direct digital control) and energy management at the installed energy equipment.

Data coming from all distributed intelligent processors is stored, via communication cards, in a common database and processed thereafter. This database is operated by a graphical work station to provide the requested information to the energy operators in an easy-to-use format, which also constitutes the main server of the system.

Generally, the operator-system link applications, responsible for making transparent and convenient for the end user to consult the information, analyze the data and generate reports from all the integrated subsystems, reside inside this graphical work station (Figure 1).

In most BMS, the system is based in modular server/client architecture capable to accommodate different configurations: from cases with only one server to configurations that require several servers and workstations interconnected through LANs (local area networks) or WANs (wide area networks, large computer system network capable of covering the whole world). The largest and most known WAN network is the Internet.

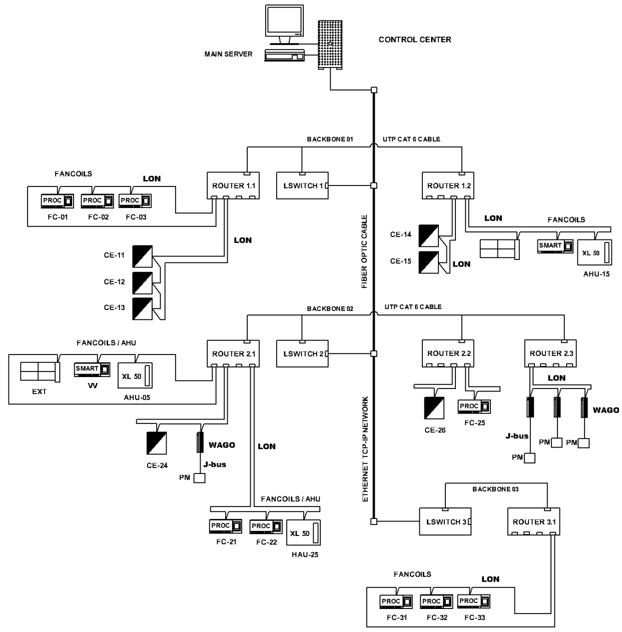

Figure 1. General control system architecture

The application packages for communicating with the distributed intelligent processors reside in the server and update the relational databases in real time. The main server also acts as a file server host, where the graphical information (screens design, images, etc) is stored. End user work station represents the graphical link between the server and the operator.

Industry trends to solve the problem of building control systems integration heads toward open communication protocols that would allow systems integration from different manufacturing companies. Several examples of these protocols are the systems based on TCP-IP, LonWorks, MODBUS, BACnet, OPC, etc. [11, 12].

The described systems have been developed to integrate the different energy installations in buildings and to provide the required functionalities to manage them.

The aim of this paper is to present the definition and implementation of a new EMCS capable to respond to buildings energy efficiency strategies by controlling the BMS and facilitating demand response actions to improve energy savings, fields that have not been tackled so far in the current control systems. Furthermore, the customer use of flexibility strategies in energy consumption is crucial for the effective integration of distributed energy resourc-

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es and CO_2 emission reduction. To achieve this demand response capability, the customers must identify building energy uses and schedules, as well as decide *when* and *how much* energy would not be willing to consume. Active demand-side participation can decrease supply side agents' market power and help these markets to achieve a better operation [13].

This paper is organized as follows: Section 2 is devoted to analyze the new functionalities introduced by the proposed EMCS. Its physical architecture is presented in Section 3 and the software components and applications development are discussed in Section 4. In Section 5 the implementation of the EMCS in the Universitat Politècnica de València is described. The obtained results of the system are described in Section 6 and, finally, some conclusions are drawn in Section 7.

2. New EMCS Features

In the previous section, the architecture and typical features of the current control systems is described, where the effectiveness of these for integrating the different technologies and facilities is shown [6, 7]. However, all these systems have been developed based on market needs such as building facilities integration and control, providing the BMS with the necessary capabilities to achieve this goal.

On the other hand, thanks to the advance of telecommunication in the last decades, today there is a possibility of the necessary hardware to implement a complex control system [14], and powerful software is capable to manage it. Also, nowadays advanced databases exist capable to store and handle lots of data [15].

Nevertheless, the need for defining and developing flexible and useful applications capable of using different systems and taking the most out of them has been detected. New aims can be defined for the control systems: improvement of energy efficiency systems and facilitate users' interaction with demand response programs.

Current control systems present several constraints. This is why it is necessary to raise innovative designs and introduce a new EMCS with additional developments. The EMCS includes the following general features [16, 17]:

● User interaction with the system is set through a web platform, which avoids the need of installing specific software at each work station. The web has been developed to allow the access to different user profiles.

● System architecture uses TCP-IP protocol, so it is not necessary to perform specific wiring to implement the system.

● The system performs and stores electrical magnitude measurements of the different facilities. The EMCS provides a specific application for data acquisition, generating an easy-to-use and extend database. Besides, the software considers anomalous situations such as communication lack with measurement equipment, making a posterior available data treatment. Therefore, it is an important improvement with respect to current BMS which are at the moment not acquiring energy consumption measurements, or if doing so, they are not storing and treating the energy data adequately.

● It is independent of users' geographical dispersion since it enables management by all users from just one and only control center.

● Since the EMCS has been entirely developed at UPV, from its architecture to the applications, it provides an enormous flexibility to the system, thereby facilitating the maintenance and updating of the entire system. The BMSs available in the market have specific applications developed by commercial trademarks, but can not be extended or adapted to the specific needs of new goals. With the comprehensive EMCS development of the system any current or future need could be implemented, as the previously mentioned ones.

● Economic reasons also influence the need for EMCS development. Commercial control systems are purchased by the number of points to be controlled and depending on the available applications; therefore, it is possible that certain desired applications might need to acquire new licenses, at a high cost, for exceeding the number of available points.

Specifically, in order to improve energy efficiency, the system:

● Has got specific applications such as the one for energy consumption surveillance, consumption control, and utilization analysis categorized in periods, etc. (Section 4).

● Has got automatic actions necessary to achieve greater efficiency. The EMCS facilitates setting connection and disconnection times, on holidays, in different operating periods, and so on. Current BMS have significant limitations on the number of different schedules that can be defined and more so they are difficult-to-use by the operator.

● Manages all acquired data and provides the necessary information without additional effort by the system operator, increasing energy efficiency in the utilization of the monitored buildings. It is not necessary for the system operator to wait for certain actions. Once they are defined, the system executes them automatically.

● Develops specific reports on daily consumption, consumption by existing tariff periods, and so on.

Specifically, to improve demand response participation:

● It Integrates all actors that can participate in a demand response program, such as program administrator, aggregators, utilities, electrical grid operators and, most

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importantly, participating customers.

● Constitutes an area of communication between different actors (consumers, suppliers, generators, etc.), which facilitates the interaction and thus, increases trust amongst them. This is a fundamental aspect for the implementation of demand response programs, since it enables energy exchanging products and services in a completely dynamic manner.

● Different participants can react to external variables such as energy or gas price fluctuations, restrictions on networks supply, renewable energy availability, etc., since building facilities are controlled.

In summary, an innovative energy management system developed entirely to meet these objectives presents major improvements over existing ones, both in flexibility and the new features it brings. The goal of the developed system resides on the implementation of new tools and techniques to improve the management of the different energy resources used in existing controlled facilities. The energy efficiency and the control of distributed loads it implies that important energy and economic savings could be achieved, which means a reduction in the environmental impact. These tools allow customer managers to measure energy consumption, to store and manage data, to control energy consumption (i.e. by adjusting the timetable for different loads) and to watch power not to exceed a pre-fixed set point. Additionally, these tools enable obtaining reports and results about energy consumption, so energy demand forecast can be easily estimated.

In conclusion, a new information application to improve energy efficiency and the interaction between the different energy agents has been created (Figure 2).

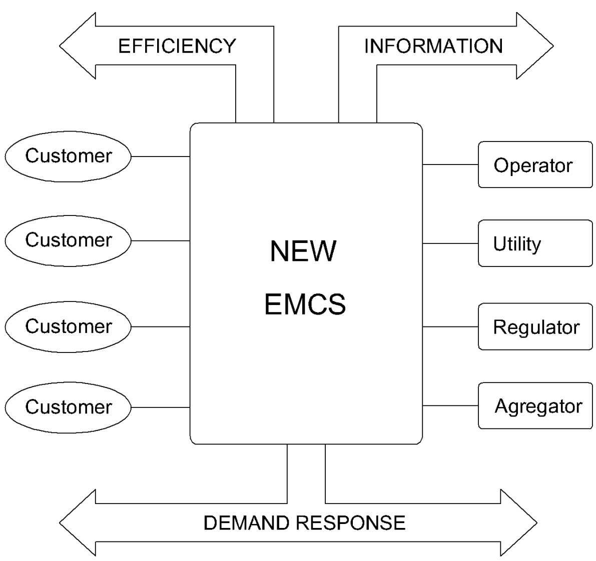

Figure 2. EMCS components

This innovative system brings something new; establishment of orders that building maintenance technicians are not introducing into the system because of it is complex and difficult to them or because they do not have the adequate software.

3. EMCS Physical Architecture

One of the fundamental characteristics of the EMCS is the possibility of communicating with facilities which are far away from each other, and gathering all the information in a central server. TCP-IP Ethernet communication is used, which permits an easy and fast access to the system [16].

Thus, in the architecture of the EMCS, the system components are located in two different sites: one is inside the controlled buildings (the customers), where electrical measurements are taken and control actions are performed. The other one is the control center, where data is stored and a main server manages all the other different applications (Figure 3).

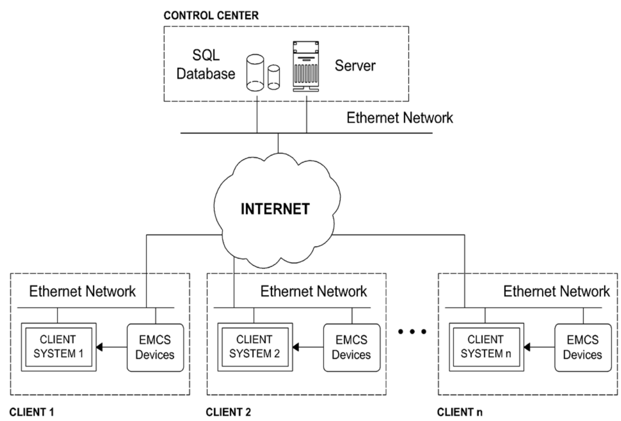

Figure 3. Architecture of the EMCS

3.1 Customers Approach

In order to acquire the necessary measurements and to interact with the facilities, the following devices have to be installed:

● Communication gateway. The gateway sets the communication line between the server and the different measurement and control components. The protocol used between the computer and this gateway is TCP-IP client-server. This device is able to discriminate between components that have permission to access data from others those are not enabled. The commercial device chosen is Telemecanique ETG100 Ethernet gateway [18].

● Data acquisition central unit. This device measures the most relevant electrical magnitude as power, current

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and voltages, as well as other ones related to power quality. It is important to collect the data of the initial status of the site in order to analyze future actions to perform. Additionally, it allows assessment of the success of adopted actions, comparing the final and initial energy status. The commercial device used is the Power Meter 710 Merlin Gerin [19]. Current transformers (I_1A / 5A) selected for the particular point are required (Figure 4).

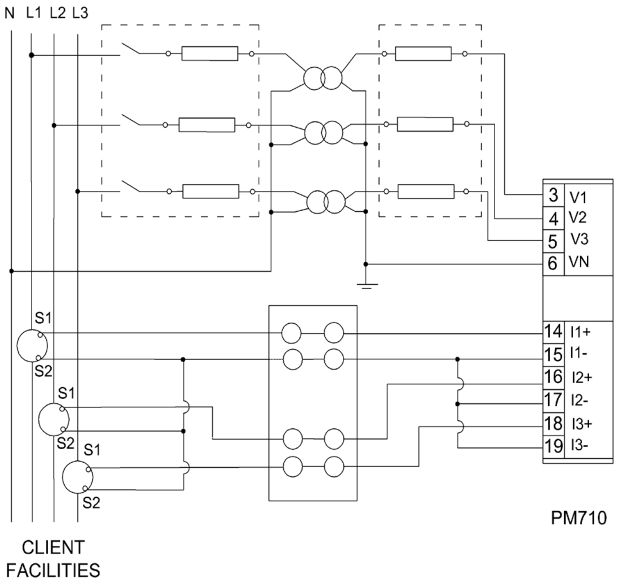

Figure 4. Connection of the data acquisition central unit PM710

● Users performance device. It is necessary to be able to act on the customer with both digital and analog operations. In addition, devices capable of making decisions locally using the instructions from the server, but independent of it, must be used. The commercial element chosen for it is the programmable logic controller-Telemecanique Twido PLC [14, 20, 21]. This will obtain input signals for controlling and certificating the system, and generates the output signals for implementing control actions on the user.

● In the electrical panels, it is necessary to install electrical control devices such as switches, contactors, relays, etc. to adjust the input and output circuits of the PLC to the controlled power system. Relays and contactors installed for the system will be of "normally closed" type to ensure that a supply voltage failure on the control panel does not interfere with the customers' facilities.

3.2 Control Center

Main server. This device works as a database, applications and web server. Gathered data are located in this server, as well as the software used to analyze and manage it. Additionally, the main server works as a web server; therefore it is the support for a secure communication via Internet. The commercial device used in the system is Intel Server System Xeon SR2520SAXR2U with 4 Gb memory DDR2 of 667 MHz, with 2 microprocessors Intel Xeon Quadcore 5405 of 2.0 GHz, 3 hard drives of 320 Gb Serial ATA and 1 DVD. Hard drives are configurated in a mirror backup mode.

Auxiliary server. It is used as a development server, where all the new applications are checked and work data is stored. Its main mission is based on centralizing the information, which implies a higher level of security. Moreover, it stores backup copies of each application in the main server. This is the reason why the auxiliary server is also a redundant station, so it could work as an autonomous server if the main one fails.

Workstations. They will be used to implement the software integrated in the servers, as well as the necessary engineering tasks to perform the different applications.

Besides, the EMCS introduced in this article interacts with the existing BMS, providing these ones with the additional functionalities to perform the required actions to improve energy efficiency and participate in demand response programs. The EMCS must not substitute the existing BMSs but must be complementary on it and should be able to interact with them. The existing BMS systems should be used for the purpose they were designed, controlling the facilities and supporting building operation.

This interaction will take place in a dedicated panel where the actions sent by EMCS shall be performed by the existing BMS (Figure 5). In the case where EMCS does not specify any actions, the BMS should operate as usual [16].

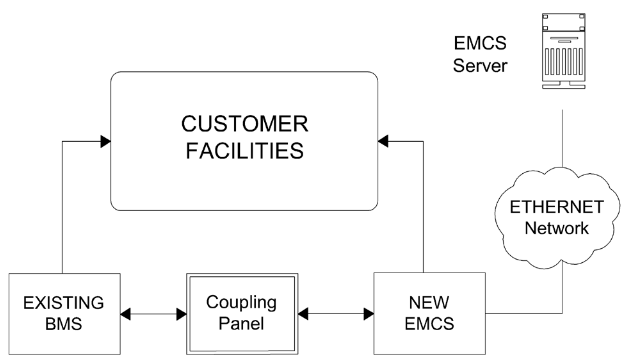

Figure 5. Interaction between the EMCS and the existing BMS

4. EMCS Software Components

As previously mentioned, EMCS is based on a web site on Internet, meaning that data could be reviewed in every computer without having to install any specific software. This also enables users to access databases and applications in an easy-to-use way [22-27]. This website is available at the following address: www.derd.upv.es.

The developed EMCS consists of different applications, some of them allow the user a more adequate management of the energy demand; and others are focused on improving the energy efficiency, however all of them are necessary for any considered demand response program:

● Consumption data gathering from customers

● Performance of control actions in facilities

● Storage and management of all the information in a secure database

● Applications development for users

The most promising applications already developed are:

4.1 Building Monitoring (Acquisition)

A reliable monitoring application is used to avoid data losses. For that purpose, adequate maintenance of the measurement devices and databases has to be performed. The existing Ethernet network is used for communication and control purposes, so it is not necessary to do any other specific wiring. For that reason, installation costs are reduced.

This application includes the following features:

● The database system which is implemented in SQL Server that provides a great functionality and has no major technical constraints to the system [22, 24].

● Every hour all measurement points are checked, taking into account their metering intervals. If any loss occurs to some extent, the system notifies through e-mail or the web page.

● Database tables' extension is taken into consideration, so an automatic partitioning is carried out each year.

● It considers the special days of spring time change, with an hour less, and autumn with an extra hour.

● It provides consumer daily report, monthly, tariff periods, and so on.

This application improves the existing control systems in data processing and storage, facilitating the posterior analysis of the information and minimizing the information errors.

Figure 6 presents the stored measurement data for a particular metering point. In the same website it is showed the control lines whose consumption depends on the measuring point represented.

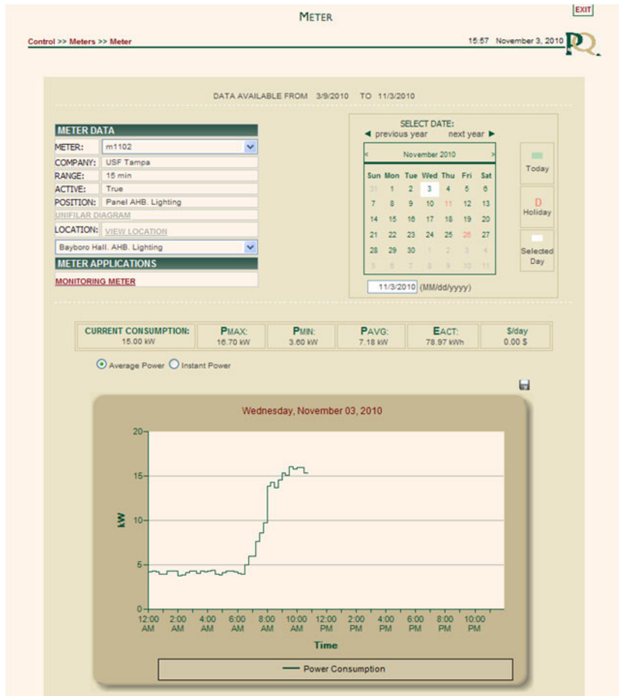

Figure 6. Web site. Meter main page

4.2 Planning Application

This application enables on/off scheduling for each control line of the system. By structuring the lines in measurement point, any on/off action taken in one of them, will be reflected in the meter point where the line hangs.

In this application, two types of planning are possible:

● *Weekly Planning*: operation hours are assigned to different weekdays. It is possible to specify 7 different schedules, one per day, and this schedule is repeated each week. Furthermore, you may define different schedules with different priorities for each period of the year, each time running on the highest priority.

● *Specific Planning*: It is defined as a special operation for a specific date, such as holidays, vacation, etc. There are 3 types of planning for specific days. *Daily*: determined planning is executed only the selected days. *Monthly*: planning for a selected day is executed every month. *Annual*: determined day planning is repeated for the specified date, every year.

This application improves the availability in the BMSs because it is more manageable, and has easier data entry and no limitation on the number of schedules as the existing systems usually present.

4.3 Vigilance Application

The aim of this application is to watch the daily electricity consumption every quarter of an hour at each facil-

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ity. When the tolerance threshold is overloaded, an advice message is sent to the manager´s cell phone or e-mail (Figure 7). It is very important for this purpose to establish the threshold to be applied properly. This information is gathered in specific building audits in order to determine the most adequate values. As this service is carried out permanently, anomalous situations can be detected very quickly, which in turn enables time and cost savings.

It is also possible to define weekly and daily surveillance, considering in a given date (i. e. holiday) where consumption is desired to be different. This application does not exist in the current control systems, since it enables making automatic comparison with historical data.

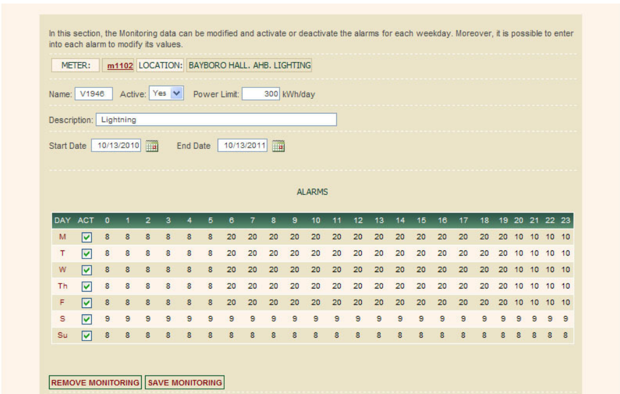

Figure 7. Web page. Vigilance application page

4.4 Peak Power Control Application (PPC)

This software allows controlling the maximum power which is demanded anytime, so penalties due to values higher than the contracted power are avoided. Thus, the client is able to control the electricity bill penalties for power excess, and improve the management of their electricity contracts by optimizing the contracted power.

Maximum power handling is done via a line controlling that have certain permissions. Lines are characterized by a code that defines the feeding loads type (Table 1).

Table 1. Line types in the PPC application

Code	Circuit name	Security level
0	Lighting	10
1	Outside Lighting	10
2	Transit Lighting	10
3	Parking Lighting	10
4	AA Split machine	5
5	AA General	10
6	AA Fan coil / AHU	5
7	AA Production	0
8	AA Parameter	10
9	Extraction	5

The parameters, which must be defined for each line controlled in the application and are necessary for PPC are:

● *Shutting capacity*: Power cut by the system when an active line is turned off, provided that equipment is on.

● *Time off*: It is the longest period that the application PPC sets the line continuously in off-state during a determined event, passing this time the line goes to on-state automatically.

● *Recovery time*: Period in which it is not possible to re-select the line after a shutdown action applied. After this time, the line becomes available to be turned off by the system.

The security level is classified according to Table 2 and used by the application with the following classification:

● Security level 0-4: Lines between these security values consist of the first group of lines which could be select to turn off by the application in case power exceeds the limit set. Any line on this level can be switched off.

● Security level 5-9: Lines with this security level comprise the second group of lines. The lines in this group will only be turn off when there are no more lines from the first group.

● Security Level 10: This third group includes the lines that can not be shut down. Therefore, they are not managed by the PPC application for achieving a power consumption reduction at any time.

Table 2. Security level in the PPC application

Security level	Line action
0-4	First Group
5-9	Second Group
10	Not shutting down

The application estimates in real time which is going to be the active power consumption during the subsequent periods in order not to exceed the maximum contract value within each quarter of an hour. To do so, the system defines two *Operating Modes*:

● *Pessimistic mode*: In this application mode, it starts turning off the lines before reaching the peak power limit defined:

$$E_{LIM} = E_{CONT} - D \cdot E_{CONT}$$

where:

E_{LIM} : Energy limit in which the lines actions start.

E_{CONT} : Maximum energy to be consumed at a given instant according to the contracted power. This value is calculated every minute and reseted every 15 minutes.

D : Deviation parameter, which indicates the energy

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percentage that is added or subtracted depending on which mode is chosen.

● *Optimistic mode*: In this mode the application starts shutting down the lines once the defined peak power limit is reached, expecting an energy consumption reduction in the sequence:

$$E_{LIM} = E_{CONT} + D \cdot E_{CONT}$$

4.5 Baseline Application

For each meter the baseline is calculated every day at 00:00h, considering previous days' measurement data (Figure 8). Currently the system implements a heuristic method which considers historical data of the last year and outside temperature forecast.

It is suitable to integrate this method in the EMCS, since it already has a database with historical measures from all the meters, and a great computation capacity and, since it is connected to Ethernet, it can automatically obtain forecasts of temperature, humidity, etc. from servers that provide such data.

Current control systems do not provide this application and which on the other hand is necessary for managing the actions taken by various participants in a demand response program.

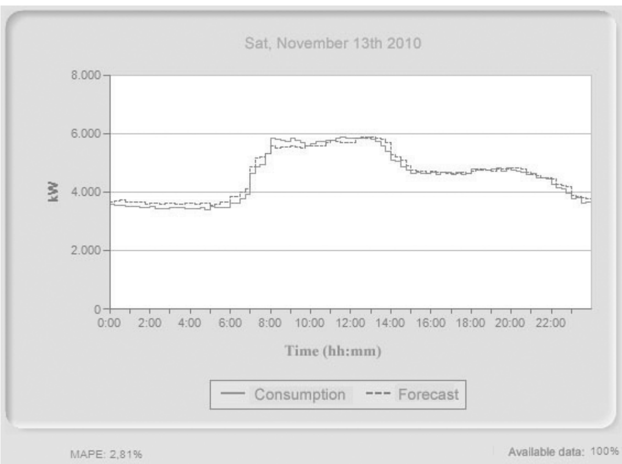

Figure 8. Web Page. Baseline application page

4.6 Maintenance Application

It performs all necessary operations to maintain the system in an adequate state. Thus, every hour it verifies that all applications are active on the server, checks the lines status each 10 minutes, performs auxiliary calculations necessary for the different applications, maintains user permissions, etc.

Other additional services that are provided by the EMCS system are:

● Responsibilities assignation.

● Raising awareness and sensitization on energy saving.

● Interaction between the different users.

5. EMCS Implementation

The project started in February 2007 and since December 2009 savings have been estimated at values of more than 850 k€, while the total cost of the project has been about 2 M€ (Table 3). What is more, it is expected that savings are higher when the EMCS is in full operation. Presently, there are already 67 UPV buildings integrated in the EMCS.

Eighty three control boxes and 236 metering points have been installed, while 2,387 lines are now being controlled.

Table 3. Cost of installed equipments

Device	Description	Cost (€/u)	No. (u)
Power Meter	Installation Power Meter 710 Merlin Gerin with 3 current transformers	654	236
Gateway	TSXETG100 Telemecanique	615	78
PLC	TWDLCAA40DRF 16 outputs, 24 inputs	813	81
Panel	Control box	750	83
Controlled devices	Relays and contactors. Connections and wiring.	250	1,953
Temperature sensor	Sensor TTA-250/F	453	2
Luminosity sensor	Sensor ELV 741	1,853	2

The EMCS carries out more than 2,500 control actions every day.

During the implementation, meters have been installed in the following electrical points:

● Main panel of the electrical system at each building

● Emergency supply main circuit breaker to obtain the total consumption of the building.

● Specific air-conditioning panel, since it is the end-use (independent process) in which control has focused on. This is because HVAC systems present the greatest possibility for energy efficiency improvements in the studied facilities.

● Specific parking panels.

● Some specific panel for interior lighting with several controlled lines.

● Measurement data is obtained out of the transformers´ output.

● Public lighting at specific electrical panels.

For improving energy efficiency in the facilities, it is necessary to perform certain actions in different circuits.

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For example, the air-conditioning installation shall be forced into the air handling units, fan coils, etc., when necessary.

It is also necessary to turn off lighting circuits, flow regulators connection at certain times, etc. Furthermore, the lines, circuits in which some control action can take place by EMCS control, are defined under different types [28]:

● Lighting.

● Outside lighting.

● Public lighting.

● Parking lighting.

● General air-conditioning.

● Air-conditioning production.

● Air-conditioning fan coil.

● Split air-conditioning equipments.

● Extractors.

Also, two sensors have been installed to measure:

● Outside temperature. Outside temperature may be obtained at each point. For this, an external temperature probe has been installed and the PLC has been extended with an analog input module. Specifically, the expansion module selected is the TWD-AMI8HT. The commercial temperature probe selected is the TTA-250 / F model [29].

● Outside Lighting. Luminosity sensor has been installed, in order to acquire data for this variable; concretely the commercial device selected for this purpose is the ELV 741 [30].

With temperature data it may be controlled the actions in the air-conditioning lines while the lighting lines are controlled with luminosity data.

The implementation impact on different system components is described in the following sections.

5.1 Impact on the Facilities Energy Consumptions

Usually, cost of electricity consumption in university premises and similar infrastructures is very high, mainly due to the following causes:

● There is no optimum management. Usually the person who manages the electricity in a building is the same that manages other services (water, air-conditioning, general maintenance, etc)

● Electricity contract is not the optimum (not enough studied).

● There is no place where users and maintenance managers can get in touch.

● Users are not aware of the energy problem.

The development of this system improves the energy management, because:

● Energy consumption is measured, so it can be controlled and reduced. In addition, there is a responsibility assignation that means that the responsible manager is more careful because he knows the building energy consumption levels and he is responsible for energy data acquisition.

● Electricity consumption during out-of-work-hours is perfectly known, so different strategies can be applied.

● New guidelines on energy use may be proposed.

Previous studies carried out about energy management in commercial buildings [3-5] showed that reductions of 8% can be obtained by only watching consumption trends. Total reduction can be up to 20% if additional active controls are performed.

5.2 Impact on Human Habits

Other important impact is the achievement of a social energy commitment. This project promotes the best use of energy by the different people forming the university community (professors, students, resource managers, services and staff) or the facilities. Thus, responsibilities for each collective are promoted in the following areas:

● Maintenance service: Control of air conditioning system and common areas' lighting.

● Students and professors: Air-conditioning and lighting in classrooms and lighting in restrooms.

5.3 Impact on the Facilities

There are two situations, which are: buildings with and without control system that integrates various facilities. In the first case, as discussed earlier (section 3.2), the EMCS provides orders to the BMS, which performs the adequate actions for turning off the necessary equipment. In the second case, EMCS performs the control directly on the facility with the installation of the required equipment (relays, contactors, etc.).

Some proposals about different equipment that is usually not controlled in analyzed buildings are included below. In order to manage these devices some actions have been implemented:

● Autonomous air conditioning (AC) devices (split units, roof-top, etc.):

Problem: Some AC individual devices, installed in offices and little rooms, remained switched on during nights or weekends.

Solution: Permission relays have been installed in series with the control circuit of machines. These relays are connected to the control system, which avoids AC devices to stay connected during nights or weekends. The payback is shorter than 2 years.

● Centralized HVAC systems

Problem: Some HVAC centralized devices remained switched on during nights or weekends. Nevertheless, the control of these systems was usually centralized and easy to adjust, but timetables were not optimized.

Solution: Permission orders are given by the EMCS to the local control system installed for chillers/heaters and groups of fans. This option avoids HVAC devices to remain connected during nights or weekends. Moreover, other control options have been performed, for example disconnection of chillers/heaters on peak hours, since fans can use the thermal inertia of the system. The payback is shorter than 2 years.

● Lighting

a) In common areas

Problem: Usually, lighting in common areas was excessive during the day. Additionally, some lights were switched on during the whole day.

Solution: Permission relays have been installed - in series - to main lines of common lighting areas that are switched off from time to time. These lines are switched off when lighting in the area is not necessary (during night, weekends and holidays). In addition, twilight switches have been installed and timetables for connection are now adapted in order to optimize the luminosity level (adaptation of switching timetables in accordance with seasonality).

b) In classrooms/conference halls

Problem: Sometimes there were empty classrooms where lights stayed switched on.

Solution: Presence detector units have been installed in series with switches in order to control the lighting.

c) In restrooms

Problem: Light in restrooms was switched on during all the day.

Solution: Presence detector units or timer switches have been installed. Energy savings of about 60% are being achieved. The payback is not higher than 3 years.

● Electronic Equipment

Problem: Obviously, the electronic equipment (computers, printers, videos) in offices, in general, and in university buildings, in particular, is very important. Energy demand of electronic devices in universities represents up to 15% of overall peak demand [31]. Sometimes, electronic equipment was switched on during the whole day.

Solution: It is analyzed the number of connected devices and the users are made aware to bring them into suspension mode. In the university there are 4,000 computers connected during night period of the 10,000 used during the day.

5.4 Demand Response Capability

Throughout the implementation of the EMCS system, various power lines are controlled. When managing a large number of buildings, the control over the available power becomes very large. As the number of monitored buildings increases, the power to be controlled also increases. Currently, EMCS is managing over 2.5 MW, only in air-conditioning lines. Such power can be used to respond to price signals that reach the system via the Internet or from a FTP server.

The EMCS provides the necessary infrastructure, capable of participating in electricity markets where power disconnection could be offered as a service to the grid. Furthermore, since the consumed energy is perfectly known in the different facilities, the electricity contract can be optimized, so that the electricity bill is reduced.

In this new framework, energy consumers could have influence over the price and quantity of generated energy, so customers may offer energy not by producing it, but by not consuming it. In this way, this system would enable demand response to be monitored by different agents, and price signals may be provided [13].

A common framework for the different energy actors has been created, where real-time information can be accessed according to access profiles. Moreover, the information provided will enable the utility to offer customized contracts to the customers.

Using the Baseline application, an estimation of certain facility consumption is obtained (Figure 9), information that can be used to establish the necessary compensation mechanism required in a demand response program.

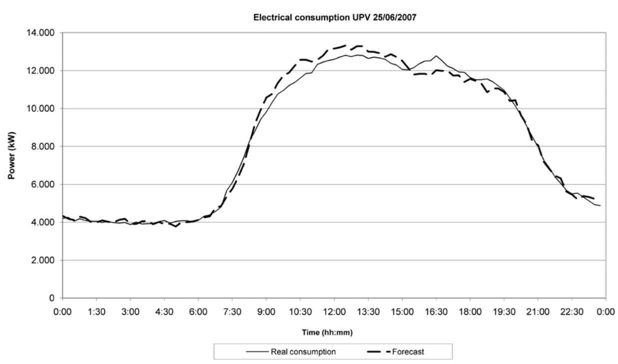

Figure 9. Baseline calculated

This EMCS is expected to contribute to the improvement of operation and management in electricity systems, since the access to centralized and controlled loads through a website provides an environment where the operator of the grid, utilities and the consumer are able to interact.

Management options proposed here may imply the reduction in the necessity of new generation plants and new transport lines, that means a significant reduction of the environmental impact (reduction of 1 Ton CO_2 emissions

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per MWh) and a reduction of needs and costs of electricity transport and system operation.

For example, in Europe there are about 4,000 colleges and universities, so this project has a huge potential for this type of infrastructures [31].

6. Obtained Results

Considering all the proposals in this work as an outcome of the implementation of the EMCS system substantial energy saving has been calculated. This includes:

● Permanent savings in HVAC systems. In conducting the initial audit, prior to the installation of the system in the buildings, set points, schedules, timers, etc. are modified obtaining a permanent better facility operation.

● Savings on lighting. Using presence detectors together with EMCS actions a reduction in lighting consumption in common areas with external lighting has been achieved.

● Savings as a result of daily monitoring of the facilities. The maintenance technicians are more dedicated since the system monitors and stores energy consumption, even in off-working hours.

● Savings in holiday periods by better adjusting the schedule planning.

● Savings by EMCS daily actions: They have been mainly achieved by controlling the HVAC devices. The results are quantified comparing the consumption during a normal day with the EMCS functioning (EMCS ON) and without doing this actions (EMCS OFF). Only implementing this action, consumption reductions in working days for these devices have been calculated in 315 €/day, whereas savings of 636 €/day and 910 €/day were achieved on Saturdays and Sundays or on holidays respectively (Figure 10).

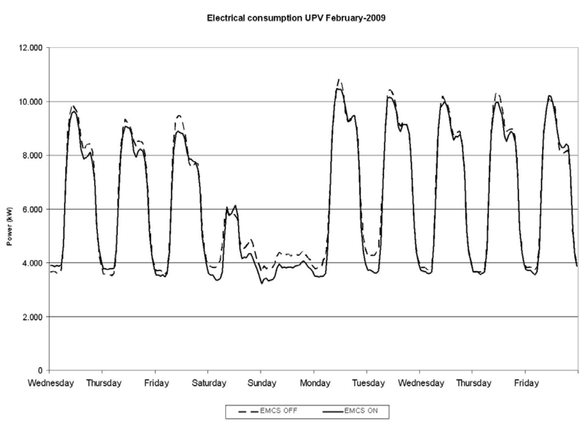

Figure 10. Energy consumption in the UPV with and without EMCS

Savings are very important in common areas lighting, such as restrooms, corridors or halls, where reductions of 18,126€ have been got.

Following, some figures directly obtained from the EMCS reports are presented to illustrate the interesting effects in the load curve of different facilities while are being controlled. These results are used for energy and economic savings calculation, according to the control actions performed by the EMCS.

Taking into account the effect in the whole campus on Saturday days, it could be inferred that consumption during the valley period (mainly on night) has been reduced, unless the total consumption during the day suffers an increment due to construction new buildings in the university.

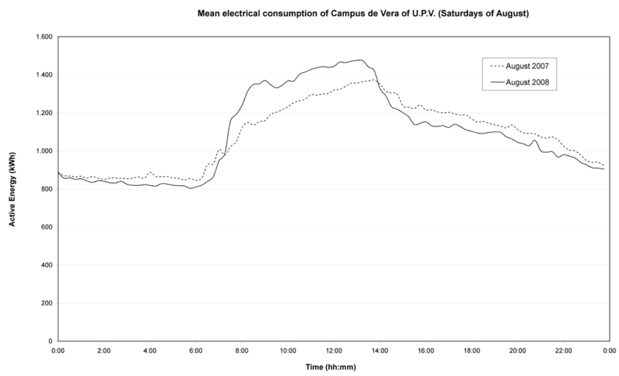

Figure 11. Consumption on Saturdays in August 2007 and 2008

As it is shown in Figure 11, the mean consumption in 2007 on Saturdays was 104,008 kWh and 104,347 kWh in 2008. Nevertheless, when only valley periods (from 0:00 to 7:00 and from 14:00 to 24:00) are considered, it is easy to check that consumption has been reduced in about 5 % (from 69,614 kWh to 66,458 kWh a day) periods in which EMCS action are performed.

A similar effect is obtained in Sundays and vacation periods. Figure 12 represents load curve for the whole campus on a holiday day, August 15th 2006, 2007 and 2008.

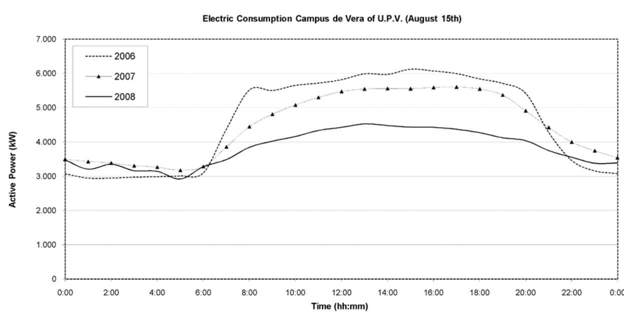

Figure 12. UPV consumption on August 15th

Consumption in 2006 is 111,734 kWh, 108,166 kWh in 2007 and 92,223 kWh in 2008, so a 15 % reduction has been achieved since the EMCS´ implementation. It has been achieved because of the proper space cooling device management, since some HVAC machines were switched on during the whole day on vacation before implementing the EMCS.

EMCS provides significant savings in air conditioning and common areas lighting, allows daily consumption monitoring, facilitates energy bills verification, permits scheduling adjustment for vacations and holidays planning, controls the peak power consumption, and provides air conditioning management on daytime and daily basis.

In Figure 13 there is an analysis of the consumption of a teaching building with 4 floors and 8,323 m^2 area (7B-7E ETSID). It can be noted that there are significant reductions in energy consumption due to switching-off of the cool production 30 minutes in advance at 21:00, so that thermal inertia of the system is used to keep the temperature range under control. Additionally, the starting time is delayed for 30 minutes in the morning and 30 minutes in the evening, which also produced noteworthy energy savings.

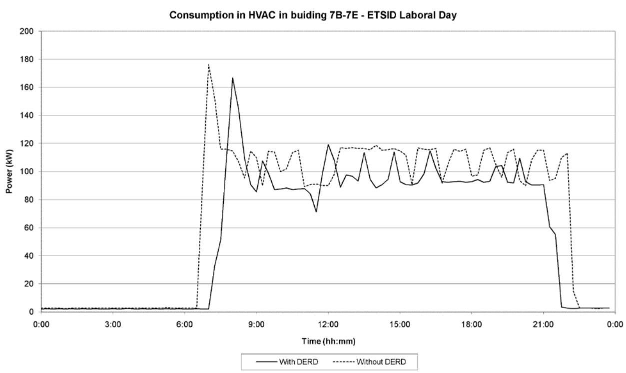

Figure 13. Energy consumption in building 7B-7E ETSID

As it is shown in the figure, consumption is reduced from 1,720 kWh to 1,392 kWh, which implies savings of 19 %. If only periods from 0:00 to 8:00 and from 21:00 to 24:00 are considered (valley periods), savings of 179 kWh are achieved.

7. Conclusions

A new energy management and control systems (EMCS) has been created to help the customer to use energy more properly. This EMCS includes a set of new tools and techniques in order to improve the management of different energy resources used in existing facilitates, resulting in a reduction in energy consumption, increasing overall efficiency and the control of the distributed loads. The university campus is selected to install the developed EMCS since it encompasses many service enterprises including healthcare delivery, sports facilities, businesses in research parks, as well as overall faculty and student services.

The EMCS is based on a secure website to inform and to get in touch with different agents that could be interested in the use of available distributed energy resources, as generation, storage and demand response. It allows the facility managers to measure energy consumption, to store and manage data, to control energy consumption and to watch power not to exceed a pre-fixed set point.

Currently, the Institute for Energy Engineering (IIE) is working on a project with a utility to define a new electricity contract, which values control power available. Within this project IIE is developing the necessary applications to manage the power available through the EMCS as an information exchange platform.

Energy consumption would be measured, so it could be controlled and reduced. As it is shown in this paper, the EMCS is able to achieve decrements of 20% with active control.

Lastly, another impact is the achievement of a social energy commitment towards effective energy control in service enterprises.

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References

[1] M. W. Ellis, E. H. Mathews. Needs and trends in building and HVAC system design tools. Building and environment, No. 37, pp. 461-470, 2002.

[2] Yiqun Pan, Rongxin Yin, Zhizhong Huang. Energy modelling of two office buildings with data center for green building design. Energy and buildings, No. 40, pp1145-1152, 2008.

[3] C. Selcuk Canbay, A. Hepbasli, G. Gokcen. Evaluating performance indices of a shopping centre and implementing HVAC control principles to minimize energy usage. Energy and buildings, No. 36, pp. 587-598, 2004.

[4] E. H. Mathews, D. C. Arndt, M. F. Geyser. Reducing the energy consumption of a conference centre. A case study using software. Building and environment, No. 37, pp. 437-444, 2002.

[5] G. Escrivá, C. Álvarez, I. Valencia. Method for modelling space conditioning aggregated daily load curves. Application to a university building. Energy and Buildings, doi:10.1016/j.enbuild.2010.02.020

[6] X. García Casals. Analysis of building energy regulation and certification in Europe: Their role, limitations and differences. Energy and buildings, No. 29,

  DOI: https://doi.org/10.30564/jcr.v2i1.576

pp. 381-392, 2006.
[7] Tianzhen Hong, S.K. Chou, T.Y. Bong. Building simulation: an overview of developments and information sources. Building and environment, No. 35, pp. 347-361, 2000.
[8] Honeywell International Inc. Características de los sistemas de control. Available in http: //www. honeywell. com /sites /es /Automation - Control-Solutions. htm, 2009
[9] Siemens building technologies Ltd. Desigo insight. Switzerland, 2009
[10] Johnson&Controls. Metasys connectivity resources manual. Bacnet system integrator. Milwaukee, 2008
[11] W. Kastner, G. Neugschwandtner, S. Soucek, H. M. Newman. Communication systems for building automation and control. Proceedings of the IEEE, No. 6, Vol. 93, June 2005
[12] Documentación protocolo LON. Available in www. lonmark.org/products/guides.htm, 2009
[13] C. Álvarez, M. Alcázar, G. Escrivá, A. Gabaldón. Technical and economical tools to assess customer demand response in the commercial sector. Energy conversion and management, No. 50, pp 2605-2612, 2009
[14] Telemecanique. Constituyentes de control industrial de Telemecanique, 2007
[15] Microsoft Corp. Manual SQL Server 2005. Available in www.microsoft.com/ spain/sql/productinfo/overview/default.mspx, 2005
[16] G. Escrivá, M. Alcazar, C. Alvarez. Integral management system for the energy efficiency improvement in commercial facilities: Application to the Polytechnic University of Valencia. International conference on renewable energy and power quality (ICREPQ'09), April 2009.
[17] F. Mugarra. Desarrollo de un sistema para la gestión optimizada de los recursos energéticos distribuidos. PFC. Director Dr. G. Escrivá. Universitat Politècnica de València, marzo 2006
[18] Telemecanique. Documentación Pasarela ETG100 de Telemecanique. Available in www.telemecanique.com/Product/index/system/architectures/Connexium, 2006
[19] Schneider Electric S. A. Power Logic Manual, 2005
[20] Twido. Manual de funcionamiento de TwidoSoft. Spa. Schneider Electric, Versión 3.2, 2006
[21] Controladores Programables Twido. Guía de referencia de hardware. TWD USE 10AS. Schneider Electric. Versión 3.2, 2006
[22] Microsoft Corp. MSDN Seguridad en ASP. NET. Available in www.microsoft.com/ spanish/msdn/botica/menu/asp_sec.mspx, 2006
[23] Business Objects. Manual de Crystal Reports. Available in www.vb-mundo.com/ tutoriales/Crystal-Reports/17.html, 2006
[24] Microsoft Corp. Manual SQL Server 2005. Available in www.microsoft.com/ spain/sql/productinfo/overview/default.mspx, 2005
[25] Microsoft Corp. Visual Basic.net. Available in http://msdn.microsoft.com, 2008
[26] Microsoft Corp. Visual Studio 2005. Available in http://msdn.microsoft.com, 2008
[27] Microsoft Corp. Internet Information Services (IIS). Available in http://msdn. microsoft.com, 2008
[28] L. Buil. Diseño e implementación de medidas de eficiencia energética en edificios de la U.P.V. PFC. Director D. G. Escrivá. Universitat Politècnica de València, mayo 2007
[29] STA/TTA. Captadores y transmisores para temperatura ambiente. 4-20mA, 2 hilos por pt100. Available in www.domout.com, 2007
[30] Hagner. ELV-741 Luminosity sensor. Available in www.hagner.se/pdf/elv741.pdf, 2005
[31] European association for education of adults. Available in http://www.eaea.org, accessed November 2008

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