

## Possibilities of Using Fuel Cells for Energy Generation in Greek Hotels

John Vourdoubas<sup>1</sup>

### Abstract

Hotel buildings consume large amounts of energy covering their heat, cooling and electricity requirements. Fuel cells are very efficient energy systems co-generating heat and electricity. Their use in the hotel industry is so far limited. The possibility of using fuel cells in Greek hotels is investigated. A preliminary estimation was made of the capacity of a stationary fuel cell generating heat and electricity in a medium-size Greek hotel with 200 beds operating throughout the year. It was found that the capacity of a MCFC providing all the annual required electricity and the largest part of the required heat in the hotel is 80 KW. Its cost is estimated at 240,000 € while its annual carbon emissions due to its operation are estimated at 56.1 kgCO<sub>2</sub> per m<sup>2</sup> of the hotel's covered surface. Fuel cells have advantages and drawbacks compared with solar energy systems which are currently used in Greek hotels for heat and power generation. They can play an important role in the future, as sustainable distributed generation systems, in the Greek tourism industry. Promotion of their use requires governmental support regarding legal and financial issues, particularly in subsidizing their capital cost which is currently high compared with other energy systems.

**Keywords:** electricity, fuel cell, Greek hotels, heat, solar energy, sustainability

### 1. Introduction

Hotels utilize energy for covering their requirements in air-conditioning, lighting, hot water and operation of various electric devices. Fuel cells are new sustainable energy systems which are very efficient in co-generating heat and electricity. They are fueled with H<sub>2</sub> or natural gas and their carbon emissions are low. Therefore fuel cells could play an important role in the new low carbon green era. Investigation of the possibility of using fuel cells in hotels is important because they could provide both the electricity and heat required for covering almost all of their energy needs. There are not many hotels reported so far globally with fuel cell installations although their use results in many benefits. They can utilize a low carbon fuel like CH<sub>4</sub> or a zero carbon fuel like H<sub>2</sub> while they can co-generate a guaranteed amount of heat and electricity with high overall efficiency. The share between the generated heat and electricity by the fuel cell is almost similar with the hotel's requirements. Although use of fuel cell systems has not been reported so far in Greek hotel industry, they could be compared with solar energy technologies which are currently used in various Greek hotels for separate heat and power generation.

### 2. Literature survey

#### 2.1 Energy consumption in hotels

**Tsoutsos et al, 2013** have reported on low energy hotels with reference to an EU funded project from the Intelligent Energy Europe program. The authors presented the rationale of the “nearly-zero energy hotels” project aiming to support the hospitality industry in adopting green energy technologies. They stated that the specific energy consumption in hotels was considered at 350 KWh/m<sup>2</sup> provided by grid electricity and fossil fuels. In order to reach a nearly-zero energy hotel level, their specific annual energy consumption should be reduced at 100 KWh/m<sup>2</sup> while 80% of it would be provided by renewable energy sources (RES). **A report on energy use in European hotels has been published, 2011.** The report mentioned that heat ventilation and air-conditioning (HVAC) accounts for approximately half of their total energy consumption while hot water production accounts for 15% of their total energy demand.

Lighting accounts for 12-18% while energy used in electric machinery and devices accounts for the rest. According to this report the most commonly used renewable energy sources in the hotel industry are solar energy and biomass. **Kapiki, 2010** has studied the energy management in hotels in Thessaloniki, Greece.

<sup>1</sup> Mediterranean Agronomic Institute of Chania, 73100, Chania, Crete, Greece Tel: +30-28210-35020, Fax: +30-28210-35001, E-mail: [vourdoubas@chania.teicrete.gr](mailto:vourdoubas@chania.teicrete.gr)

The author mentioned that energy costs have a share of 3-6% of their total operating costs while HVAC accounts for almost 50% of their total energy consumption. She also stated that various simple green practices could be adopted in hotels reducing their energy consumption in a cost-effective way. **Yao et al, 2017** have studied the energy consumption characteristics of hotel buildings in Shanghai. Analyzing energy consumption data from forty five (45) three-, four- and five-star hotels, the authors found that electricity had a share of 75% of their total energy consumption. They also mentioned that their specific annual energy consumption varied between 215.7 KWh/m<sup>2</sup> to 279.8 KWh/m<sup>2</sup>. **Santamouris et al, 1996** studied the possibility of energy conservation in Hellenic hotels. Analyzing energy data from 158 Hellenic hotels, the authors estimated their overall annual energy consumption at 273 KWh/m<sup>2</sup>. They also mentioned that it is possible to reduce with energy refurbishment their overall energy consumption by 20%. **Vourdoubas, 2016** realized a study on energy consumption in five summer-operating hotels in Crete, Greece. The author estimated their average annual energy consumption at 149 KWh/m<sup>2</sup> or 19.4 KWh per night spent (p.n.s.) while their average annual carbon emissions were at 93.2 kgCO<sub>2</sub>/m<sup>2</sup> or 12.1 kgCO<sub>2</sub>/p.n.s. He also stated that grid electricity was the main energy source used, having a share at 60-85% in their overall energy mix. **An EU report, 2017 for best environmental management practices in the tourism sector** stated that energy consumption in hotels is distributed at 31% for space heating, 17% for domestic hot water (DHW), 15% for cooling, 12% for lighting, 5% for cooking, 4% for office equipment, 4% for ventilation, 3% for refrigeration and 9% for other uses. It also proposed benchmarking values for total annual energy consumption less than 180 KWh/m<sup>2</sup>, while for both HVAC and water heating it was less than 75 KWh/m<sup>2</sup>.

## 2.2 Use of sustainable energy technologies in hotels

**Cannistrato et al, 2016** have studied the technical and economic feasibility of a heat and power co-generation (CHP) plant for a hotel located in Northern Italy. The authors mentioned that in winter the heat generated will be used in the production of DHW, in space heating and in air treatment renewal, while in summer it will be used in DHW production and in air treatment renewal. They also stated that the CHP plant was profitable with a payback time of approximately four years. **Perfetto et al, 2016** have studied the creation of zero-energy hotels combined with sustainable mobility in the islands of the Aegean Sea, Greece. The authors mentioned that combining solar passive energy techniques with solar energy technologies the creation of net zero energy consumption hotels is feasible. They also stated that excess electricity generated by a solar-PV system could be used for H<sub>2</sub> production, by water electrolysis, which could power electric vehicles in the hotel. **A report on renewable energy opportunities for island tourism by IRENA, 2014** analyzed the potential contribution to the island tourism sector of four renewable energy technologies including solar water heating, solar air conditioning, sea water air conditioning and solar-PVs. It was concluded that these four technologies, compared with the typical alternatives already used, are cost-effective with attractive pay-back periods. **Ramos et al, 2017** have reported on solar energy systems providing heating with reference to the solar-thermal and the hybrid PV-thermal systems. The authors mentioned that solar energy offers many advantages in meeting heat requirements in many applications. They also stated that although solar heat is a mature energy technology, heat storage is required due to the intermittence of solar irradiance. **Parpairi, 2017** has investigated the possibility of using sustainable energy technologies in small-scale Greek hotels. The author mentioned that apart from some successful examples of renewable energy use in large hotels, there are various difficulties for their application in smaller hotels. She stated a list of reliable and cost-effective renewable energy technologies (RET), including solar energy technologies, which could be used in small-scale Greek hotels. **Bischoff et al, 2016** have studied the use of RET in a new hotel building in Amsterdam, Holland. The authors, using computer simulation, investigated the economic and environmental feasibility of using solar-PVs, micro-wind turbines and CHP systems in a hotel building. Their results indicated that solar-PV installation is profitable provided that enough space availability exists either on the rooftop of the hotel or in a nearby building. **Vourdoubas, 2015** has realized a case study for net zero carbon emissions hotels in Crete, Greece. The author stated that energy consumption in a summer-operating Cretan hotel is 50% for AC, 15% for DHW, 10% for lighting, 15% in the kitchen and laundry and 10% in other uses. He also mentioned that the combined use of solar thermal energy, solar-PV energy and ground source heat pumps could provide all the annually required energy in the hotel, zeroing its net carbon emissions.

## 2.3 Fuel cells

**A report for policy makers regarding the use of fuel cells by Clean Energy States Alliance, 2011** mentioned that the overall efficiency of four types of fuel cells including Proton exchange membrane (PEMFC), Phosphoric Acid (PAFC), Molten Carbonate (MCFC) and Solid Oxide (SOFC) varies between 80% and 90%. It also stated that their capital cost is in the range of \$2,500 - \$4,500 per KW for 1-200 KW sizes while their CO<sub>2</sub> emissions are at 0.49 kgCO<sub>2</sub>/KWh, assuming that the fuel is natural gas converted to H<sub>2</sub> within the fuel cell. **A report on fuel cells for stationary CHP applications by ERA, 2015** found that four types of fuel cells are suitable for stationary applications including PEMFC, PAFC, MCFC and SOFC. The report mentioned that their power efficiency is in the range of 50-60% while their overall efficiency could exceed 90%.

For commercial systems with capacity between 300 and 1,400 KW, their capital cost in 2014 varies between 4,600 \$/KW to 10,000 \$/KW while their operation and maintenance (O&M) costs vary between 36 \$/MWh to 45 \$/MWh. **Weidner et al, 2019** have reported on global deployment of large capacity stationary fuel cells. The authors mentioned that until 2018 more than 800 MW large stationary fuel cells with a rated capacity above 200 KW each have been installed globally. Most of them have been installed in the USA and South Korea while the dominant technologies include MCFC, SOFC and PAFC. They also stated that the main barriers for their deployment are related with their durability, reliability and high capital cost. **Wang et al, 2018** have studied the techno-economic challenges of fuel cells' commercialization. The authors mentioned that fuel cells are new energy systems having many advantages compared with their competitors and they could play an important role in the future low carbon green economy. However, they stated, fuel cells have some drawbacks related with their durability and reliability which should be overcome in order to be broadly commercialized. **Lipman et al, 2004** have investigated the fuel cell economics related with power generation from PEM fuel cells. The authors mentioned that stationary PEMFCs suitable for commercial buildings with a size of approximately 250 KW would become profitable when their price is at \$700/KW assuming that the natural gas price would be at \$4/GJ.

## 2.4 Use of fuel cells in hotels

**El-Gohary et al, 2008** have evaluated the use of fuel cells in floating hotels in the Nile, Egypt. The authors investigated the use of sustainable energy systems in the Nile's floating hotel "Lady Mary". Their results indicated that a MCFC using LNG could power "Lady Mary" in a cost-effective way with low environmental impacts. **Horiuchi et al, 2001** have reported on the application of fuel cell power units in hotels. The authors stated that a 100 KW grid-connected PAFC has been installed on the rooftop of the Nagoya Sakae Washington hotel Plaza in Nagoya Sakae. They mentioned that the generated electricity was covering part of its electricity needs while both low-temperature heat, at 50°C, and high-temperature heat, at 90°C, were also utilized in the hotel. **A 100 KW pure H<sub>2</sub> fuel cell**, manufactured by Toshiba, is going to be installed in a new hotel located in Kawasaki, Japan. H<sub>2</sub> is going to be produced by recycling used plastics while the co-generated heat is going to be utilized in the hotel. **Tronstad et al, 2017** have studied the use of fuel cells in shipping. The authors mentioned the existing fuel cell technologies including Alkaline FC, Phosphoric Acid FC, Molten Carbonate FC, Solid Oxide FC, Proton Exchange Membrane FC and Direct Methanol FC. The electric efficiency of these fuel cells is in the range of 40-50% while their overall efficiency, including heat recovery, is at approximately 85%. **Radisson Blue Hotel installed a fuel cell in 2017** in its property in Frankfurt, Germany which generates a large share of its energy requirements. The fuel cell annually supplies 3 GWh of electricity and 2 GWh of heat in the hotel with a capacity of more than 400 rooms. **Lafayette Hotel** located in San Diego, California, USA has installed a 40-KW fuel cell system in 2010 in its 131-room building. The fuel cell generates 45% of the required electricity while the co-generated heat is warming its Olympic-size swimming pool. The payback period of the investment was estimated at 5.8 years taking into account the governmental capital cost's subsidy offered. **Sheraton San Diego Hotel and Marina** located in California, USA was planning to install a fuel cell in its 1,044-room property. Four 250 KW fuel cells were going to provide the hotel's base electricity load while the co-generated heat was going to heat its pool. **Pei Chen et al, 2014** have studied the economics of using solid oxide fuel cells in hotels in Hong Kong. The authors mentioned that a fuel cell could provide electricity, heat and cooling using absorption chillers in the hotels. They estimated that the investment's payback period is less than six years provided that a 50% capital subsidy is obtained. However, they concluded, various barriers hinder the promotion of this technology in Hong-Kong's hotels. **A report on applications of CHP systems in hotels, 2008** found that hotels with a capacity in the range of 100 to 500 rooms could install CHP systems with a capacity 60-350 KW. It is also stated that in 2007, 109 hotels in the USA were using CHP systems based on reciprocating engines fuelled by natural gas. However more CHP technologies have emerged recently including micro-turbines, fuel cells and gas turbine systems.

*The aims of the current research are:*

- a) *The investigation of the possibility of using fuel cells like solar energy technologies for covering the energy requirements in Greek hotels, and*
- b) *The sizing and the cost of a fuel cell suitable for a medium-size Greek hotel as well as the environmental impacts during its operation.*

The methodology followed includes: a) estimation of energy consumption in Greek hotels from existing literature, b) investigation of solar energy technologies which are used in hotels from existing literature, c) investigation of fuel cell systems already operating in hotels worldwide, and d) a preliminary estimation of a fuel cell system which could be used in a medium-size Greek hotel.

### 3. Energy consumption in Greek hotels

Hotels utilize energy for air-conditioning, hot water production, lighting and operation of various electric devices and machinery. As indicated in various studies, air-conditioning accounts for approximately 50% of their total energy consumption, hot water production 15%, while the rest is used in lighting and operation of various electric devices. Existing studies in Greek hotels indicated that their average annual energy consumption was at 273 KWh/m<sup>2</sup> while in summer-operating hotels in the island of Crete, it was lower at 149 KWh/m<sup>2</sup>. It is also indicated that electricity was the main energy source used in hotels. Among RES, solar energy is mainly used for hot water production and electricity generation and occasionally solid biomass for heat production. Energy costs consist of a low percentage, at 3-8%, in the total operating costs of hotels and this discourages hoteliers in small and medium-size hotels to invest in sustainable energy technologies, particularly when the investment costs are high. Energy consumption by end-use in hotels is presented in Table 1. Almost half of the energy consumption in hotels is utilized for heating purposes.

Table 1. Energy consumption by end-use in hotels

| Sector           | %   |
|------------------|-----|
| Space heating    | 31  |
| Hot water        | 17  |
| Cooling          | 15  |
| Lighting         | 12  |
| Cooking          | 5   |
| Ventilation      | 4   |
| Office equipment | 4   |
| Refrigeration    | 3   |
| Others           | 9   |
| Total            | 100 |

Source: Best environmental management practices in the tourism sector, 2017

### 4. Use of solar energy technologies in Greek hotels

Various solar energy technologies are currently used in Greek hotels for heat and electricity generation. The most important of them include:

- a) Solar water heating,
- b) Solar electricity generation, and
- c) Passive solar heating.

Solar water heating is a mature, reliable and cost-effective technology. It is broadly used during the last four decades in Greek hotels for hot water production required in guest rooms, in the kitchen, the laundry and in heating the swimming pool. Due to high solar irradiance in Greece, solar water heating is very attractive and profitable in hotels of any size covering part or all of their hot water requirements. Solar electricity generation with solar-PV systems is also attractive, particularly in the last ten years when the solar-PV's costs have been substantially reduced. Solar-PV panels can be installed either on-site or off-site in the hotel according to the net-metering regulations. Generated electricity can be either consumed in the hotel, if needed, or sent into the grid. Passive solar systems can cover part of the building's heating and cooling requirements and they are suitable for seasonal operating hotels.

Solar thermal cooling with absorption chillers is a technology suitable for seasonal operating hotels since solar energy is available when space cooling is required. However, solar thermal cooling technology is not fully commercialized yet and technology improvements are required in order to become economically attractive.

### 5. Possibility of using fuel cells in Greek hotels

#### 5.1 Fuel cell types

Fuel cells consist of distributed co-generation systems having many advantages compared with their competitors. Stationary fuel cells installed in hotels can supply clean, quiet, guaranteed and efficient energy. They can generate both the electricity and heat needed to cover the hotel's energy requirements. They are reliable devices having low maintenance needs while they create minimal on-site pollution. The primary fuel used in fuel cells is H<sub>2</sub>. Usually they are fueled with natural gas which can be converted to H<sub>2</sub> inside the device. There are four primary types of commercial fuel cells currently used in portable or stationary applications. Their main characteristics are presented in Table 2.

Table 2. Characteristics of major fuel cell types

| Fuel cell characteristics                  | PEMFC               | PAFC              | MCFC     | SOFC      |
|--|---------------------|-------------------|----------|-----------|
| Operating temperatures (°C)                | 65-85               | 150-200           | 600-700  | 700-1,000 |
| Size (KW)                                  | 5-10                | 50-1,000          | 50-1,000 | 1-3,000   |
| Oxidant                                    | Air, O <sub>2</sub> | Air, enriched air | Air      | Air       |
| Possibility for internal reforming of fuel | No                  | No                | Yes      | Yes       |
| Electrical efficiency (%)                  | 25-35               | >40               | 45-47    | 35-43     |
| Overall efficiency (%)                     | 70-90               | >85               | >80      | <90       |

Source: a) Catalog of CHP technologies, 2015; b) Fuel cells for policy makers, 2011

### 5.2 Sizing a fuel cell covering the energy needs in a Greek hotel

The capacity of a MCFC suitable for a medium-size Greek hotel operating throughout the year will be estimated under the following assumptions:

- The size of the hotel is 200 beds, its covered surface is 3,000 m<sup>2</sup> while its annual energy consumption is 220 KWh/m<sup>2</sup>,
- Energy consumption per sector in the hotel is as follows: space heating 31%, hot water production 17%, lighting 12% and operation of various electric devices and equipment 40%,
- The hotel is grid-connected and it can sell the surplus electricity generated by the MCFC when it is not needed, into the grid according to net-metering regulations,
- The electric efficiency of the fuel cell is 50%, its heat efficiency is 36%, while its capital cost is 3,000 €/KW, and
- The fuel cell should generate all the electricity required annually in the hotel, operating 8,760 hours per year, since the net-metering regulations allow its storage into the grid when it is not needed in the hotel.

The characteristics of the MCFC are presented in Table 3.

Table 3. Characteristics of the MCFC installed in the abovementioned hotel <sup>1</sup>

|  |  |
|--|--|
| Annual energy consumption in the hotel   | 660,000 KWh  |
| Heat required for space heating and hot water production   | 316,800 KWh <sub>th</sub>  |
| Electricity required in other sectors of the hotel   | 343,200 KWh <sub>el</sub>  |
| Capacity of the fuel cell for covering all the hotel's electricity needs                                   | 80 KW  |
| Co-produced heat by the fuel cell  | 252,288 KWh <sub>th</sub>  |
| Additional heat which should be provided in the hotel  | 64,512 KWh <sub>th</sub>   |
| Capital cost of the MCFC   | 240,000 €  |
| Capital cost of the MCFC per m <sup>2</sup> of hotel's covered surface                                     | 80 €   |
| Nominal power of solar-PV panels generating the same amount of electricity like the fuel cell <sup>2</sup> | 228.8 KW <sub>p</sub>  |
| Cost of the solar-PV panels  | 274,560 €  |
| Carbon emissions due to MCFC operation   | 168.17 tnCO <sub>2</sub> /year or 56.1 kgCO <sub>2</sub> per m <sup>2</sup> per year |
| Carbon emissions due to heat and electricity generation  | 0.255 kgCO <sub>2</sub> per KWh of both thermal and electric energy generated        |

<sup>1</sup> Own estimations, <sup>2</sup> Annual electricity generation by solar-PV panels=1,500 KWh/ KW<sub>p</sub>,

It should be noted that current net-metering regulations in Greece do not include the operation of fuel cells like solar-PVs but this could probably change in the future. The proposed fuel cell will cover all the hotel's annual electricity requirements and a considerable amount of its heating needs. However, additional heating will be required. The amount of the estimated additional heat needed pre-supposes that all the co-generated heat by the fuel cell will be used when it is produced since it cannot be stored for a long period.

### 5.3 Economic and environmental considerations

The electric efficiency of a MCFC, at 80-90%, is significantly higher than the efficiency of a solar-PV system, at 15-20%, generating the same amount of electricity in the hotel.

The estimated capital cost of the fuel cell is lower than the corresponding cost of the solar-PV system. However the cost of fueling the MCFC with natural gas is not zero like the cost of solar energy. Carbon emissions due to fuel cell use at 0.255 kgCO<sub>2</sub> per KWh of both electric and thermal energy generated is lower than carbon emissions due to grid electricity generation in Greece which is in the range of 0.60-0.75 kgCO<sub>2</sub> per KWh<sub>el</sub> depending on the fuel mix used. It can be compared though with carbon emissions for heat production with natural gas, at 0.20 kgCO<sub>2</sub> per KWh<sub>th</sub>, and with diesel oil at 0.27 kgCO<sub>2</sub> per KWh<sub>th</sub>.

## 6. Discussion

Hotels require almost equal amounts of electricity and heat during their operation. Fuel cells are heat and power co-generation systems which can generate the amounts required in the hotels with very high overall efficiency. Therefore they are considered efficient energy generation systems which could contribute in the mitigation of climate change. Fuel cell use in the Greek tourism industry has not been reported so far although their installation in hotels is growing worldwide. RETs, which are commonly used in the Greek tourism industry, are related either with solar thermal systems for hot water production or with solar-PV systems for electricity generation. Solar thermal systems are used for many decades in Greece while solar-PV systems are used only during the last few years due to the sharp drop in their cost. Solar energy systems require large spaces for their installation while a fuel cell can be installed in a relatively small space. Both solar energy systems and fuel cells are low-noise operating devices. Solar-PV systems can sell the excess generated electricity, when it is not needed into the grid according to net-metering regulations. These regulations could also facilitate the future propagation of fuel cells in various applications. Fuel cell prices are expected to drop due to their increasing use in many sectors as well as in technological improvements. However, their further penetration into the market requires financial support regarding their capital cost. Solar energy technologies and fuel cells used in the hotel industry have advantages and drawbacks which are presented in Table 4.

Table 4. Solar energy technologies and fuel cell characteristics used in hotels <sup>1</sup>.

| Technology                                   | Fuel cells  | Solar thermal technology - flat plate collectors                     | Solar-PV technology  |
|--|---|--|--|
| Energy generation                            | Co-generation of heat and power                                 | Heat production  | Electricity generation   |
| Fuel used                                    | H <sub>2</sub> or CH <sub>4</sub>                               | Solar energy   | Solar energy   |
| Guaranteed or intermittent energy generation | Guaranteed heat and power co-generation                         | Intermittent energy generation: heat storage is required             | Intermittent energy generation: electricity storage is required      |
| Capital required                             | High capital investment   | Low capital investment   | High capital investment  |
| Energy efficiency                            | High efficiency in the co-generation of heat and power (80-90%) | Moderate heat efficiency (30-35%)                                    | Low power efficiency (12-20%)  |
| Net-metering requirements                    | Net-metering regulations are desirable                          | Net-metering regulations are not required                            | Net-metering regulations are necessary                               |
| Land availability                            | Large surfaces are not required for installation                | Large surfaces are required for installation                         | Large surfaces are required for installation                         |
| Technology use                               | The technology is not broadly used                              | The technology is broadly used in regions with high solar irradiance | The technology is broadly used in regions with high solar irradiance |
| Technology reliability                       | Medium reliability energy systems                               | High reliability energy systems                                      | High reliability energy systems                                      |
| Capital cost                                 | 3,000 €/KW  | 300 €/KW <sub>th</sub>   | 1,200 €/KW <sub>p</sub>  |

<sup>1</sup> Own estimations

## 7. Conclusions

Use of sustainable energies in the hotel industry would assist in the reduction of its carbon footprint and in the mitigation of climate change. Fuel cells consist of distributed co-generation systems with high-energy

efficiency and low carbon impact. They could be used in the tourism industry providing the required heat and electricity for a hotel's operation which has an almost equal share in their total energy consumption.

Investigation of the possibility of using fuel cells in the Greek tourism industry has indicated that their use has many advantages. A MCFC at 80 KW could provide all the electricity required annually, at 343,200 KWh, in a medium-size Greek hotel with 200-bed capacity operating throughout the year. It could also provide almost all of the heat needed. Comparison of fuel cells with solar energy systems used in hotels indicated that fuel cells have various advantages. The cost of the required MCFC is estimated at 240,000 € or 80 € per m<sup>2</sup> of the hotel's covered surface. Annual carbon emissions due to operation of the fuel cell are estimated at 56.1 kg CO<sub>2</sub> per m<sup>2</sup>. Our findings indicated that fuel cells could play an important role in providing energy in Greek hotels taking into account the expected future reduction in their capital costs and the improvements in their durability. Further research should be focused on a detailed cost analysis of fuel cells' use in the Greek hotel industry.

## References

- Bischoff, J. M. A., Hensen, J. L. M., Hassan Mohamed, M., & Philips, C. (2016). Renewable energy technology feasibility study for a new hotel building in Amsterdam. *REHVA Journal*, (October), 21-27.
- Cannistrato, G., Cannistrato, M., Galvagno, A. & Trovato, G. (2016). The co-generation in service hotel complexes. A case study, Recent Advances in Energy, Environment and Financial Science, In Proceedings of the 12<sup>th</sup> International Conference on Energy, Environment, Ecosystems and Sustainable Development, Venice, Italy, 29-32/1/2016, pp. 19-25.
- Catalog of CHP technologies. Technology characterization. Fuel Cells, 2015. Retrieved at 16/3/2020 from [https://www.epa.gov/sites/production/files/2015-07/documents/catalog\\_of\\_chp\\_technologies\\_section\\_6.\\_technology\\_characterization\\_-\\_fuel\\_cells.pdf](https://www.epa.gov/sites/production/files/2015-07/documents/catalog_of_chp_technologies_section_6._technology_characterization_-_fuel_cells.pdf)
- Combined heat and power. An energy efficient technology choice for Mid-size and large hotels, (2008). Retrieved at 13/3/2020 from <https://nepis.epa.gov/Exe/ZyNET.exe/P1004NJ8.TXT?ZyActionD=ZyDocument&Client=EPA&Index=2006+Thru+2010&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5Czyfiles%5CIndex%20Data%5C06thru10%5Ctxt%5C00000009%5CP1004NJ8.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=hpfr&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL>
- El-Gohary, M.M, Naquib, A. & Ammar, N.R. (2008). Evaluation of applying fuel cell technology in Nile floating hotels, 7<sup>th</sup> International conference on role of engineering towards a better environment, Alexandria, Egypt, 20-22/12/2008.
- Fuel cells: Briefing papers for state policy makers, 2011, Clean Energy States Alliance. Retrieved at 10/3/2020 from <https://www.cesa.org/assets/2011-Files/Hydrogen-and-Fuel-Cells/CESA-Fuel-Cells-Brifing-Papers-for-State-Policymakers-Aug2011.pdf>
- Fuel cell technology to power Radisson Blue hotel. Retrieved at 11/3/2020 at <https://www.edie.net/news/6/Fuel-cell-technology-to-power-Radisson-Blu-hotel-energy/>
- Horiuchi, Y. & Nakajima, N. (2001). Application of fuel cell power units to hotels, *Fuji Electric Review*, 47(1), 7-8. Retrieved at 11/3/2020 from [https://www.fujielectric.com/company/tech\\_archives/pdf/47-01/FER-47-01-000-2001.pdf](https://www.fujielectric.com/company/tech_archives/pdf/47-01/FER-47-01-000-2001.pdf)
- Hotel chain looks to fuel cells for power. Retrieved at 13/3/2020 from <https://www.renewableenergyworld.com/2005/02/18/hotel-chain-looks-to-fuel-cells-for-power-22673/#gref>
- Hotel Energy Solutions (2011), Analysis on Energy Use by European Hotels: Online Survey and Desk Research, Hotel Energy Solutions project publications. Retrieved at 10/3/2020 from <http://www.nezeh.eu/assets/media/fckuploads/file/Reports/10.HESreserch.pdf>
- Kapiki, S. (2010). Energy management in hospitality: A study of the Thessaloniki hotels, *Economics and Organization of Future Enterprises*, 1, 78-97.
- Lafayette hotel case study, Historic hotel sets new green standard with fuel cell combined heat and power. Retrieved at 12/3/2020 from <https://sites.energycenter.org/sgip/profiles/fuel-cell-combined-heat-and-power-lafayette-hotel-case-study>
- Lipman, T.E., Edwards, J.L. & Kammen, D.M. (2004). Fuel cell system economics: comparing the costs of generating power with stationary and motor vehicles PEM fuel cell systems, *Energy Policy*, 32, 101-125.
- Parpairi, K. (2017). Sustainability and energy use in small scale Greek hotels: Energy saving strategies and environmental policies, *Procedia Environmental Sciences*, 38, 169-177. doi: 10.1016/j.proenv.2017.03.099

- Pei Chen, M.J. & Ni M. (2014). Economic analysis of a solid oxide fuel cell cogeneration/trigeneration system for hotels in Hong-Kong, *Energy and Buildings*, 75, 160-169. DOI: 10.1016/j.enbuild.2014.01.053
- Perfetto, G.M. & Lamacchia, F.P. (2016). Zero Energy Hotels and Sustainable Mobility in the Islands of Aegean Sea (Greece). *International Journal of Clean Coal and Energy*, 5, 23-36.  
<http://dx.doi.org/10.4236/ijcce.2016.52003>
- Ramos, A., Guarracino, I., Mellor, A., Alonso-Alvarez, D., Childs, P., Ekins-Daukes, N.J. & Markides, Ch.N. (2017). Solar-thermal and hybrid photovoltaic-thermal systems for renewable heating, Grantham Institute, White/Briefing paper No 22, Imperial College, London. DOI: 10.13140/RG.2.2.10473.29280
- Renewable Energy Opportunities for Island Tourism, International Renewable Energy Agency, 2014. Retrieved at 11/3/2020 from <https://www.irena.org/publications/2014/Aug/Renewable-Energy-Opportunities-for-Island-Tourism>
- Santamouris, M., Balaras, C.A., Dascalaki, E., Argiriou, A. & Gaglia, A. (1996). Energy conservation and retrofitting potential in Hellenic hotels, *Energy and Buildings*, 24, 65-75.
- Styles D., Schönberger H., Galvez Martos J. L.(2017). Best Environmental Management Practice in the Tourism Sector, EUR26022 EN. doi:10.2788/33972
- Toshiba Wins Order to Supply 100kW Pure Hydrogen Fuel Cell System Fueled with Hydrogen Produced by Recycling Plastic. Retrieved at 17/3/2020 from [https://www.toshiba.co.jp/about/press/2017\\_06/pr0501.htm](https://www.toshiba.co.jp/about/press/2017_06/pr0501.htm)
- Tronstad, T., Åstrand, H.H., Haugom, G.P.& Langfeldt, L. (2017). Study on the Use of Fuel Cells in Shipping, EMSA, European Maritime Safety Agency, Lisbon, Portugal, 1, 1–108. Retrieved at 11/3/2020 from <http://www.emsa.europa.eu/emsa-homepage/2-news-a-press-centre/news/2921-emsa-study-on-the-use-of-fuel-cells-in-shipping.html>
- Tsoutsos, Th., Tournaki, St., Avellaner de Santos, C. & Verellotti, R. (2013). Nearly zero energy buildings. Applications in Mediterranean hotels, *Energy Procedia*, 42, 230-238. doi: 10.1016/j.egypro.2013.11.023
- Vourdoubas, J. (2015). Creation of hotels with zero CO<sub>2</sub> emissions due to energy use: A case study in Crete, Greece, *Journal of Energy and Power Sources*, 2(8), 301-307.
- Vourdoubas, J. (2016). Energy consumption and use of renewable energy sources in hotels: A case study in Crete, Greece, *Journal of Tourism and Hospitality Management*, 4(2), 75-87. DOI: 10.15640/jthm.v4n2a5
- Wang, J., Wang, H. & Fan, Y. (2018). Techno-economic challenges of fuel cell commercialization, *Engineering*, 4, 352-360. <https://doi.org/10.1016/j.eng.2018.05.007>
- Weidner, E., Ortiz Cebolla, R. and Davies, J. Global deployment of large capacity stationary fuel cells – Drivers of, and barriers to, stationary fuel cell deployment, EUR 29693 EN, Publications Office of the European Union, Luxembourg, 2019, ISBN 978-92-76-00841-5, doi:10.2760/372263, JRC115923.
- Yao, Z., Zhuang, Z. & Gu, W. (2015). Study on energy use characteristics of hotel buildings in Shanghai, *Procedia Engineering*, 121, 1977-1982. doi: 10.1016/j.proeng.2015.09.195