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Hoteling Cruise Ship's Power Requirements for High Voltage Shore Connection Installations

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ABSTRACT

The main objective of this paper is the presentation of a theoretical and quantitative study of the power requirements that any port considering to install and develop shore to ship connection systems must consider. Particularly, the current study focuses these requirements for cruise ship ports and their terminals. This paper provides theoretical and quantitative tools and ideas that can be used to estimate main design parameters such as frequency, voltage and power for high voltage shore connections. Some models and equations are developed aiming to be able to estimate, with acceptable quality, cruise ship's power demand for hoteling services at port. On the other hand, this article is intended to assess ship's air pollution impact populated harbour areas to decide whether alternative power supply measures are feasible. Finally, the assessment model is applied at Barcelona's cruise piers and case study is discussed. As a result of that, a daily power demand curve and the consequent air pollution study at the most crowded situation in this port are obtained.

1. Introduction

Actually, High voltage shore connection (HVSC) technologies are enough advanced for apply them to the ships that have the highest power demand at port, cruise ships. This type of ships, are such as enormous floating cities that use to have a very wide list of power consumers and services within their hoteling services.

According to their mission, cruise ships must always keep on supplying power to their services with determined power characteristics and acceptable quality. For that reason, high voltage shore connection installations, particularly on their shore-side, have to be designed in the way to supply enough power, good quality and compatible parameters. The International Standard ISO, in their standard ISO/IEC/IEEE 80005-1 High Voltage Shore Connection (HVSC) Systems - General requirements, reference (ISO/IEC/IEEE 80005-1, 2012), provides some requirements and recommendations about how to design the installation, but it does not provide any idea about how to estimate the maximum power for which the installation should be designed in function of ships that use to berth at port. In contrast, Classification Societies do not include complete requirements for the shore-side of any installation, but they include acceptable ranges for power, in which frequency and voltage variations are defined. Moreover, to design and develop these technologies, ships that use to do port calls at the proposed location must be considered because once the installation will be constructed, it must guarantee compatibility with the widest range of ships.

Then, it is not hard to understand the importance of first steps of high voltage shore connection installation's design. The accuracy of the designed installations at any port is going to determine their occupancy and consequently their economic viability.

In that way, first step in any design procedure should be

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deciding which are going to be final product characteristics or specifications. In the present case, to develop the design of an electric installation, the previous main aspects that must be considered are voltage, frequency, power demand for hoteling particularly in Barcelona's harbour, number of consumers and national grid characteristics.

Cruise ships that use power for hoteling services in Barcelona's harbor and the ISO standard shall be the starting point of consideration for deciding voltage, frequency and power demand. The maritime sector has always been a high closed sector according to ship's data privacy in many fields. Because of that, determining the exact value for that magnitudes it is not as easy as it seems. Aiming to determine all these aspects, some studies included in references; (Patrick Ericsson and Ismir Fazlagic, 2008; Brown et al., 2006; Merk, 2013; ENVIRON International Corporation Seaworthy Systems, Inc. et al., 2005); have been used because of their data collection about cruise ships using high voltage shore connection at berth, especially the one developed in San Francisco's port.

2. Theoretical Determination of Power's Quality

As has already been mentioned above, determining supplied power's magnitudes is always difficult. The difficulty resides in ship's power own production. Cruise ship's power generation on board depends basically on their wide range of power demand. That range varies between different cruise ships because the noticeable difference between their mission, small cruise ships are focused on offering lux and exclusive holidays for example, and enormous ones on being able to hold a huge capacity of passengers and a large list of entertainment activities such as theatres, casinos or nightclubs within others.

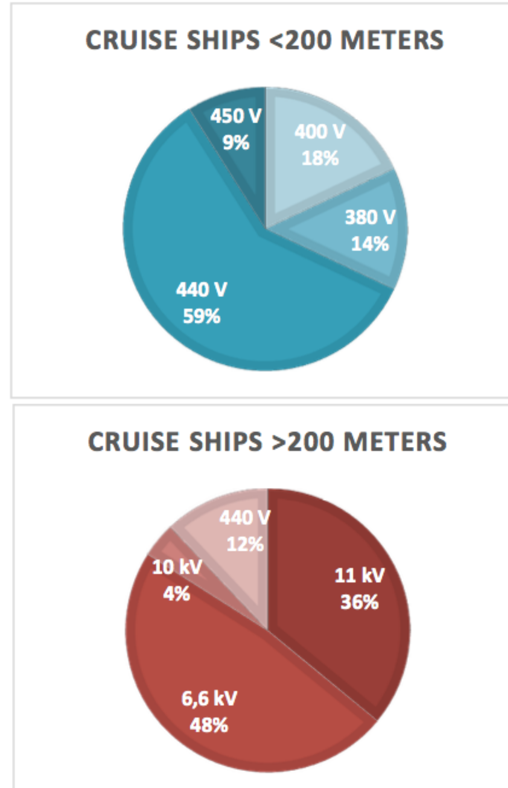
Their mission also depends on the route they are going to operate on, because of the difference on national grid's frequency between countries or continents.

Then, according to their mission, cruise ships are designed with a determined voltage and frequency. Aiming to estimate the habitual distribution of world's cruise ships voltages, voltage data obtained from (ENVIRON International Corporation Seaworthy Systems, Inc. et al., 2005) has been used to develop figure 1.

It can be extracted from it, that ship's length, which is also related with ship's size, is an important variable that use to influence on cruise ship's nominal voltage for generation on board. As it can be seen in figure 1, choosing a determinate voltage is not possible because there are many different nominal voltages in cruise ships and it will restrict the commercial target just within compatible ships and consequently the economic and environmental benefits will not be the total possible ones.

Because of that, the design determination for voltage is not based on a unique voltage. The best solution is installing some systems due to allow the global installation supply energy within the particular voltage range. In that way, all the cruise ships could use shore side electricity with any problem of compatibility. Voltage ranges obtained as a result of that study are mainly

Figure 1: Voltage percentage graphs depending on cruise ship's length on which the 50% of the listed cruise ships are under 200 meters of length



Source: prepared by the authors based on **?** data

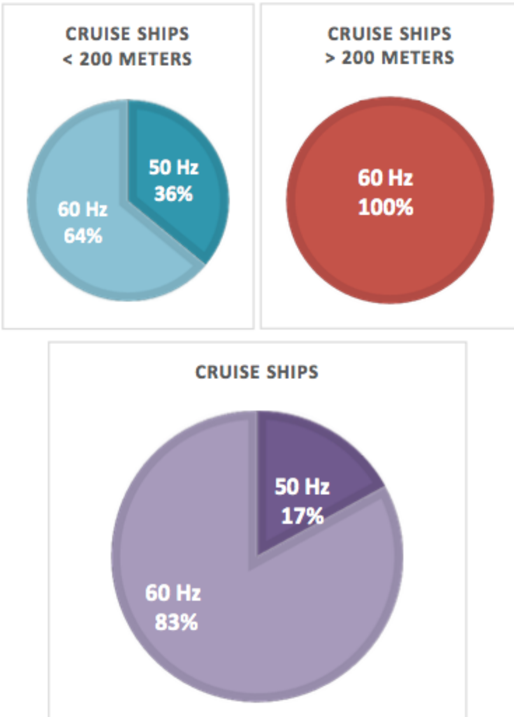
two, one medium voltage and one low voltage range. These main voltage ranges are: $6.6kV$ - $11kV$ for medium voltage and $380V$ - $450V$ for low voltage.

Frequency is easier to determinate compared with voltage. In that case, only two standard frequencies are used; the European frequency, 50Hz, and the American frequency, $60Hz$. Applying it to cruise ships, it seems that for over 200 meter ships only $60Hz$ is used. Then, once again, ship's length has a determining influence on ship's frequency.

Frequency used on board cruise ships is showed by percentages in figure 2. In that case, $60Hz$ is the most used frequency on board. But many port are considered strategical international ports for cruise ships at the sea or ocean they are situated in. So, in the way to keep that consideration, the installation shall be able to supply energy in both frequencies. That is why the design solution must consider the inclusion of frequency converters.

Finally, the design must consider national's grid characteristics because it is probably going to be the supplier of the shore to ship installation by a central substation located at the propinquity of port's installation or inside it. Then it is positive to get knowledge about how the distribution system is structured and which electrical characteristics it has.

Figure 2: Frequency percentage graphs depending on cruise ship's length and without taking it into account



Source: prepared by the authors based on **?** data

3. Estimating Models Development for Hoteling Power Demand

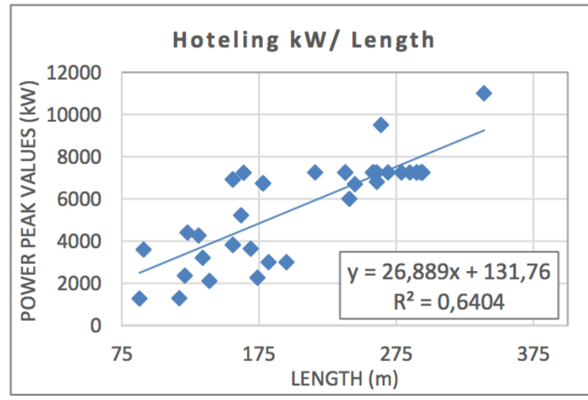
As well as deciding voltage and frequency, maximum power demand that can be required by cruise ships berthed at port should be determined aiming to be able to supply enough power with acceptable quality to all of them. Then, it would be useful to have a quantitative model to estimate cruise ship's power demand while they are at berth. That power demand is commonly known as 'Hoteling Power Demand'.

Some experimental models had been developed aiming to estimate the maximum power for which the installation must be designed. Main steps of the modeling process have been:

1. Data collection; As a result of an extended research, a complete data collection about hoteling power peak values during the connection in San Francisco's port for all type of ships was found. Related studies (Patrick Ericsson and Ismir Fazlagic, 2008) and (ENVIRON International Corporation Seaworthy Systems, Inc. et al., 2005) were the main data source.
2. Once, hoteling power demand peak values were found for 40 cruise ships, an elaborated data chart had been developed completing technical specifications of each selected cruise that appears in the study. With all these information, some hoteling power demand models had been done by the relation between how much power a cruise ship demand for hoteling and one characteristic of that ship, including, number of passengers, gross tonnage and ship's length.

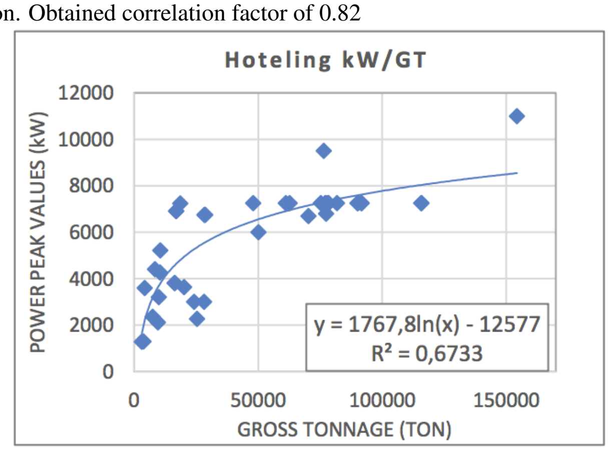
As a result of using regression methods, and testing them by studying their correlation factor, many models have been obtained. The most reliable ones are showed in figures 3, 4 and 5.

Figure 3: Model 1 - Hoteling/Length ratio by linear regression. Obtained correlation factor of 0.8



Source: Authors

Figure 4: Model 2 - Hoteling/Gross tonnage ratio by logarithmic regression. Obtained correlation factor of 0.82

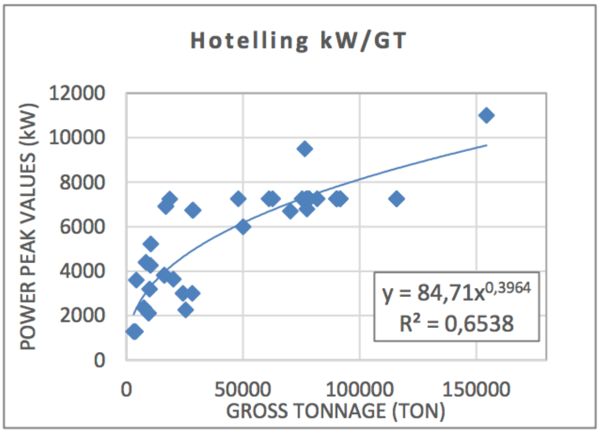


Source: Authors

Finally, after comparing all the models, the logarithmic regression between hoteling power demand and gross tonnage seems to be the one who has the higher correlation factor. Otherwise, looking the situation of each point in all the diagrams, it can be deduced that the real tendency of hoteling demand is divided in two parts, and the biggest ships are usually far from the tendency curve such as exceptional consumers. Aiming to develop a very reliable model some cruise ships with very particular characteristics have been deleted from model's data to evaluate their influence in the obtained models. The most appreciable influence take place in models 2 and 3, on which these changes modify their accuracy from 0.82 to 0.876 and from 0.808 to 0.849 respectively. These new models are showed next:

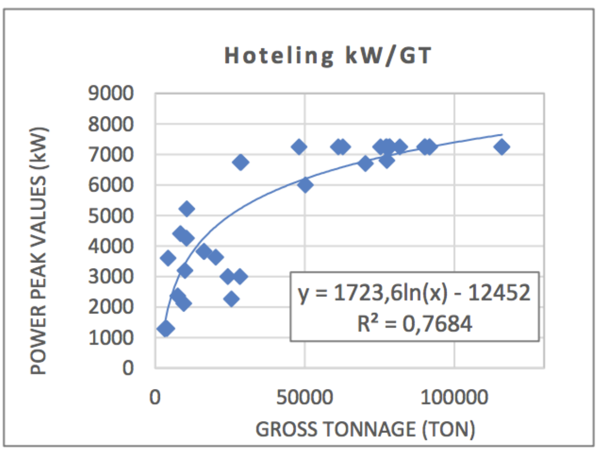
Obtaining a perfect regression is difficult because it is not a proportional increase. For that reason and for practical use all the models had been tested to consider which was better to cal-

Figure 5: Model 3 - Hoteling/Gross tonnage ratio by potential regression. Obtained correlation factor of 0.808



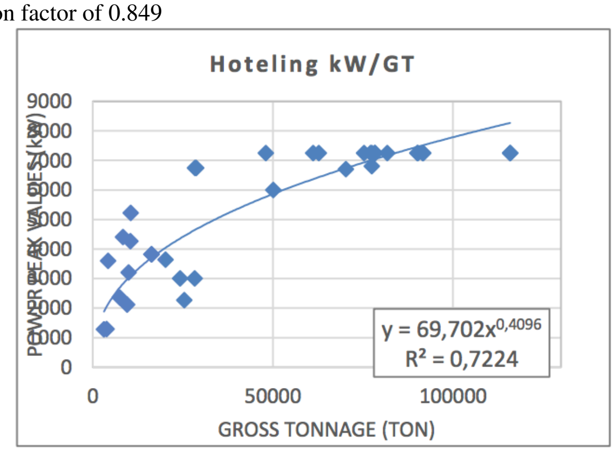
Source: Authors

Figure 6: Model 4 - Improved model from Model 2. Obtained correlation factor of 0.876



Source: Authors

Figure 7: Model 5 - Improved model from Model 3. Obtained correlation factor of 0.849



Source: Authors

culate the total demand in Barcelona's cruise piers. Although the demonstrated accuracy and correlation of the improved last two models, after testing all of them, the one that provides the highest results for power demand and the widest range of application is the one based on gross tonnage and potential tendency. Then, that model can be applied for any cruise ships. Choosing that model, the dimensioning of the installation may be over dimensioned, but this is better than dimensioning it for lower power demand, in which case, it may not be enough for supplying all the consumers.

4. Barcelona's harbour Case Study

Once models had been developed, hoteling power demand can be approached for all cruise ships and for any existing harbor. Barcelona's cruise piers have the total capacity of 9 cruise ships at the same time. According to (Barcelona's port, 2013a) and due to one of these piers is an 'extra' pier for maneuverability the installation design is going to consider just 8 simultaneous consumers. To demonstrate its application at Barcelona's cruise harbour, maritime traffic statistics and previsions from port authorities has been used to approach the common daily schedule of the biggest cruise ships that usually do port calls in the city. These cruise ships are listed below:

Table 1: Biggest cruise ships that use to do port call at Barcelona's harbour during 2013 and 2014

Ship's name	L *(m)*	GT *(ton)*
OASIS OF THE SEAS	361	225282
LIBERTY OF THE SEAS	339	160000
INDEPENDENCE OF THE SEAS	339	160000
REGAL PRINCESS	330	142000
NORWEGIAN EPIC	330	155000
MSC SPLENDIDA	333	133500
MSC FANTASIA	333	138000
CELEBRITY EQUINOX	315	122000

Source: prepared by the authors based on (Barcelona's port, 2013b,c, 2014a) where:
L= Length between perpendiculars in meters
GT=Gross Tonnage in tonnes

Aiming to obtain a daily power demand curve, gross tonnage of these cruise ships were used to substitute the variable in the chosen obtained model based on gross tonnage. As a result of that, power demand for the listed cruise ships had been approached. That power results are showed in the following table:

Table 2: Estimated power peak values required by hoteling services for cruise ships listed in 1, by using model 3

Ship's name	Hoteling (kW/h)
OASIS OF THE SEAS	11213.8
LIBERTY OF THE SEAS	9791.4
INDEPENDENCE OF THE SEAS	9791.4
REGAL PRINCESS	9339
NORWEIGAN EPIC	9669
MSC SPLENDIDA	9113.2
MSC FANTASIA	9233.8
CELEBRITY EQUINOX	8793.6

Source: Prepared by the authors

The last step was the implementation of a daily curve based on ship's habitual schedule to represent that consume during the

Table 3: Estimated habitual schedule for cruise ships at Barcelona's harbor for cruise ships listed in 1. Elaborated from (Barcelona's port, 2013b,c, 2014a,b, 2015)

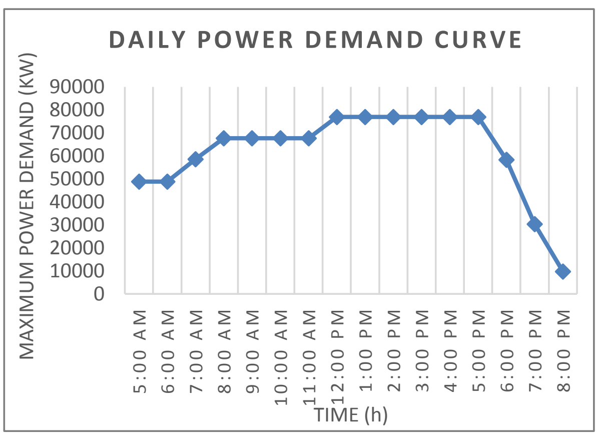
Ship's name	Arrival Time	Departure Time
OASIS OF THE SEAS	5:00 am	7:00 pm
LIBERTY OF THE SEAS	5:00 am	5:00 pm
INDEPENDENCE OF THE SEAS	7:00 am	7:00 pm
REGAL PRINCESS	5:00 am	7:00 pm
NORWEIGAN EPIC	5:00 am	6:00 pm
MSC SPLENDIDA	8:00 am	6:00 pm
MSC FANTASIA	12:00 am	5:00 pm
CELEBRITY EQUINOX	5:00 am	5:00 pm

Source: Prepared by the authors

day. The considered schedule had been summarized in table 3, showed next:

The following daily power demand curve for hoteling services, showed as figure 8, has been developed by using the mentioned model and all the exposed data in the current section:

Figure 8: Daily power demand curve developed by using model 3



Source: Authors

5. Air Pollution's reduction by using HVSC

Air pollution is the main contributor to the global warming and the climate change (Daniel J.Jacob and Darrell A. Winner, 2009). In the last few years, all international organizations have tried to elaborate rules, regulations and other type of means aiming to control and reduce emission's contribution to global warming. The reality is that sustainability is no longer a choice (Paul Polman, CEO of Unilever, 2016) and the society must face the problem and choose sustainability such as the main evolution pattern.

According to emission's impact, the last purpose of this paper is to use the obtained model to estimate air pollution from ships over Barcelona while they are at berth. According to (ENTEC UK, 2005), table 4 and 5 show an emission factor for each type of gas that contributes on air pollution and to increase global warming, produced due to power's generation by to ways. The first way is by generating it with on board auxiliary Engines using 0.1% Marine Distillate (MD) such as fuel according to the Directive 2005/33/EC, (Official Journal of the European Union, 2008). The second way is by generating it by European's generation sources such as power plants within others. The result of the comparative shows a huge reduction on pollution

Table 4: Pollution averages and pollution emission factors

Pollution Average	NO_x (g/kWh)	SO_2 (g/kWh)	VOC (g/kWh)	PM (g/kWh)
(A) Using Auxiliary Engines	11.8	0.46	0.40	0.30
(B) Using Electricity Production	0.35	0.46	0.02	0.03
$(A-B)$ Emission Reduction	11.41	0	0.38	0.27
Emission's Variation (%)	**-97.7**	**0**	**-95**	**-90**

Source: ENVIRON, refence (ENTEC UK, 2005)

Table 5: Pollution averages and pollution emission factors

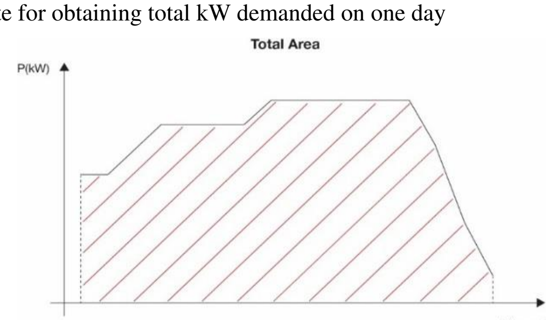
Pollution Average	CO_2 (g/kWh)	CO (g/kWh)	CH_4 (g/kWh)	N_2O (g/kWh)
(A) Using Auxiliary Engines	720	1.3	0.01	0.031
(B) Using Electricity Production	330	0.0125	0.028	0.014
$(A-B)$ Emission Reduction	390	1.29	-0.018	0.017
Emission's Variation (%)	**-54.17**	**-99.04**	**80**	**-54.84**

Source: ENVIRON, refence (ENTEC UK, 2005)

To calculate emissions per berth, as it can be seen above tables 4 and 5, time and power demand of electricity are needed to convert the averages in real values. Then, to be able to calculate them, the daily power demand curve obtained in the previous section, corresponding to figure 8, is going to be used for obtaining how much power cruise ships can consume while they are at berth during one day of the most crowded passengers traffic, August or October.The procedure used for that, was just calculating the area under the curve. That step, has been implemented by Simpson's integration method.

The result of that calculus is 957930.35 kW. Time is not needed for calculating the emissions because that power value is a result of the integration during time. The representation of that procedure is showed in the next figure:

Figure 9: Area under the obtained daily power demand curve to integrate for obtaining total kW demanded on one day



Source: Authors

Then, once the total power consumption during one day is known, the last step is multiplying it per all the averages exposed in the last section aiming to obtain estimated values for each emission type from ships. As a result of that, the following chart was developed:

Table 6: Estimated values for emission quantities from cruise ships divided in each type of pollutant during the most possible polluting day at Barcelona's cruise harbour

Type of Emission	Quantity (*kg*)	Percentage Over Total (%)
SO_x	11303.6	1.607
NO_2	440.65	0.063
VOC	383.17	0.054
PM	287.38	0.041
CO_2	689709.85	98.052
CO	1245.31	0.177
CH_4	9.58	0.001
N_2O	29.7	0.004

Source: Prepared by authors

6. Results and Discussion

The objectives of this paper, as it is mentioned in its introduction and abstract, are focused into two main facts.

First, an optimized model is developed shaped in equation form, to estimate maximum power demand that any cruise ship can demand for hoteling services while it is berthed at port. As it has been commented along all the paper, the chosen one to develop pollution's estimation was selected basing the decision on being sure that in case this model or this method would be applied to any port, in the worst case, the installation would be oversized but would be able to supply the required power. In addition, to develop the chosen model any corrections have been done as they were done for models 4 and 5. In the following table, all models are listed with their characteristics:

Table 7: Obtained model's summary, their input and their correlation factor

Model	Equation	Variable (x)	R
1	$y = 26.889 \cdot x + 131.76$	Length - meters	0.8
2	$y = 1767.8 \cdot ln(x) - 1277$	Gross tonnage - tonnes	0.82
3	$y = 84.71 \cdot x^{0.3964}$	Gross tonnage - tonnes	0.808
4	$y = 1723.6 \cdot ln(x) - 12452$	Gross tonnage - tonnes	0.876
5	$y = 69.702 \cdot x^{0.4096}$	Gross tonnage - tonnes	0.849

Source: Prepared by authors

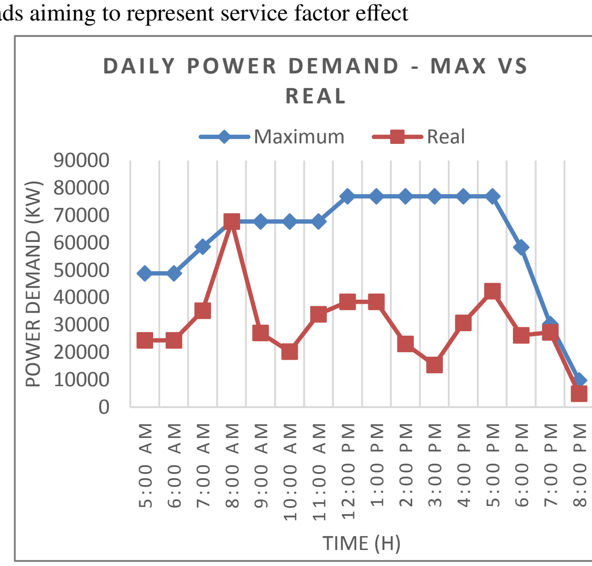
Then, it is clear to guess that model 2 is the most reliable one within the first three models developed with the whole cruise ship's list. That's why, in consequence, model 4 developed by improving model 2 is the most reliable one from correlation's factor point of view because it has the highest one. In contrast, must be considered that to develop model 4 and 5 some cruise ships have been removed from the original list used to develop models 1, 2 and 3. Because of that, these models produce better estimations than the first three models but, their application cruise ship range is not as wide as the one for models 1,2 and 3.

As regard to the obtained daily power demand curve, it must be considered that it has been developed with power peak values of the biggest cruise ships. Consequently, the installation would not probably have to supply that amount of power for one day, even if that day is the most crowded day in terms of cruise ships occupation at Barcelona's harbour. The estimation is done to know the maximum power that could have to be supplied in the worst case, but in that case, this value will not be maintained more than two hours. Then, a service factor must be considered. Aiming to improve the developed method, power's estimation value that is going to be considered is the 40% of the obtained as a result of integrating daily's power demand curve. This consideration is based on the fact that cruise ships do not demand the same amount of power simultaneously during the day.

Because of that a service factor of 0.40 have been considered. That value cannot be constant, but it is a good way to calculate an accurate estimation. This variation between real daily power demand and the calculated one is represented in figure 10.

The calculated power demand is going to variate along the year because of the seasons and the most touristic months demanded by the passengers such it can be seen in figure 11. In that way, if one year's power consumption or air's pollution would like to be developed, the developed models of that paper can be adapted for that aim.

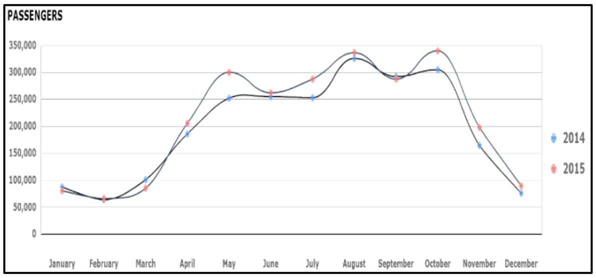
Figure 10: Comparative between daily power demand maximum values, obtained from case study, and real values, elaborated with aleatory loads aiming to represent service factor effect



Source: Authors

Second, quantify and evaluate polluting emissions. Without the consideration about the service factor, pollution results are too far from real ones because they are obtained using the developed models. But, it can be truly observed in table 6 that the amount of CO_2 which combustion engines produce has a 98% over the total emissions. Sulphur oxides emissions are the

Figure 11: Annual variation of passenger traffic through Barcelona cruise terminals during 2014 and 2015



Source: Barcelona cruise traffic statics

other big type of emissions that they can produce with an 1,6% over the total. Then, CO_2 emission's supremacy is completely confirmed. Consequently, applying the mentioned service factor results for air pollution emissions or emission averages at Barcelona's harbour must be the 40% of the obtained values due to their dependence from total power's estimation during one day. Then, the final results are:

Table 8: Final values for emission quantities from cruise ships divided in each type of pollutant during the most crowded situation at Barcelona's cruise harbour

Type of Emission	Quantity (*ton*) per day
SO_x	4.521
NO_2	0.176
VOC	0.153
PM	0.115
CO_2	275.884
CO	0.498
CH_4	0.004
N_2O	0.012

Source: Prepared by authors

The obtained results seem to be very high but to evaluate them, they must be compared with reliable values. For that reason, reference (Official Journal of the European Union, 2008) has been consulted to determine pollution contributions on ambient air quality in the city of Barcelona which is based on the Directive 2008/50/EC about air quality for Europe. That Directive, which is incorporated in Spanish laws by the "Real Decreto 102/2011" and modified by the 'Real Decreto 678/2014; (BOE, 2011) and (BOE, 2014); incorporates an assessment of ambient air quality just in relation to Sulphur dioxide, nitrogen dioxide and oxides of nitrogen, particulate matter, lead benzene and carbon monoxide. Within it group of gases, just Sulphur dioxide, nitrogen dioxide, oxides of nitrogen, particulate matter and carbon monoxide can be used for the present paper. Limit values for the protection of human health are showed in the following tables:

As it can be seen in the exposed tables, limit values are expressed by concentration units ($\mu g/m^3$ or mg/m^3). Aiming to evaluate the obtained results by using the model, volume units shall be obtained by determining an experimental volume to estimate such as the sample. The determination of the main emission area which is object of this estimation must be Barcelona's port. According to (Ajuntament de Barcelona, 2014), the highest concentration levels for Nitrogen Oxides and Particulate Matter are situated over port's whole extension. These concentrations and they distribution over Barcelona cruise piers are showed in the following figures:

Table 9: Limit values for the protection of human health according to Directive 2008/50/EC - Sulphur dioxides

Sulphur Dioxide			
Averaging Period	**Limit Value**	**Limit times not to exceed**	**Margin of Tolerance**
One hour	$350\mu g/m^3$	24/year	$150\mu g/m^3$ (43%)
One day	$125\mu g/m^3$	3/year	None

Table 10: Limit values for the protection of human health according to Directive 2008/50/EC - Nitrogen dioxide

Nitrogen Dioxide			
Averaging Period	**Limit Value**	**Limit times not to exceed**	**Margin of Tolerance**
One hour	$200\mu g/m^3$	18/year	None
Calendar year	$40\mu g/m^3$	0	None

Figure 12: Barcelona cruise piers

Source: Google Maps

Once the area with the highest concentration is identified, it is going to be considered such as the main destination of cruise emissions without considering wind effect. Aiming to estimate a volume to test the obtained results and to simplify calculations the sample which is going to be supposed for this section is a hemisphere. Its center is supposed to be located at the same distance from the furthest two berthing points and it is going to have a radius equal to 2,5 kilometers. According to the men-

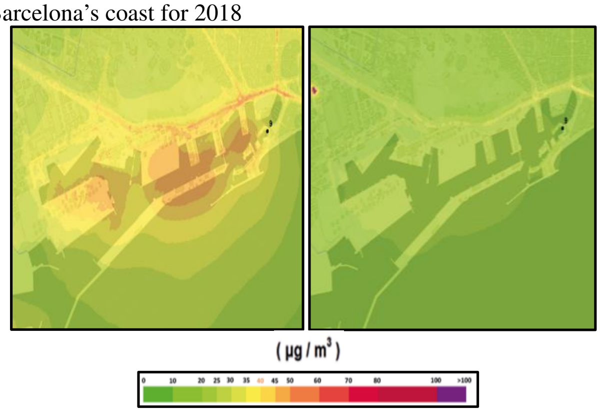
Table 11: Limit values for the protection of human health according to Directive 2008/50/EC - Carbon monoxide

Carbon Monoxide			
Averaging Period	**Limit Value**	**Limit times not to exceed**	**Margin of Tolerance**
One hour	$10\mu g/m^3$	18/year	60%

Table 12: Limit values for the protection of human health according to Directive 2008/50/EC - Particulate matter (PM-10)

PM-10			
Averaging Period	**Limit Value**	**Limit times not to exceed**	**Margin of Tolerance**
Maximum daily eight hours	$50\mu g/m^3$	35/year	50%
Calendar year	$40\mu g/m^3$	0	20%

Figure 13: Nitrogen oxides (left) and Particulate matter10 (right) concentration distribution, based on calendar year average and forecasted at Barcelona's coast for 2018



Source: Ajuntament de Barcelona

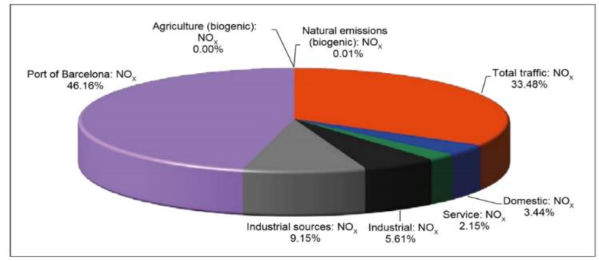
tioned data, the hemisphere volume would be $3,2724 \cdot 10^{10} m^3$. Then using the estimated volume, concentrations can be estimated for the obtained results expressed by mass units. The used sampled is considered for one day. In the following table concentration values for the gases limited by the Directive 2008/50/EC are showed and contrasted with limit values for the protection of human health.

Table 13: Comparison between limit values for the protection of human health according to Directive 2008/50/EC and obtained results

Type of Emission	Concentration	Limit Value	Difference Against Limit Values
SO_x	$138.15\mu g/m^3$	$125\mu g/m^3$	+10.52%
PM	$3.51\mu g/m^3$	$50\mu g/m^3$	-92.97%

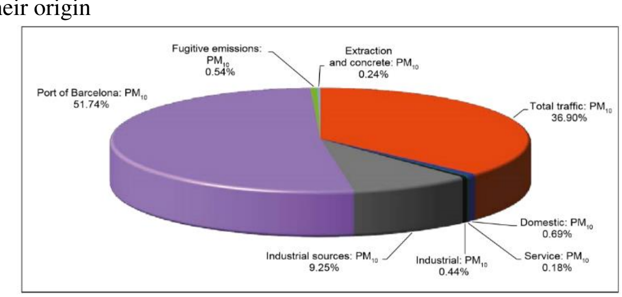
Just Sulphur oxides and Particulate Matter can be contrasted with limit values provided by the Directive because these values for each gas, as it can be seen in tables 9, 10, 11, 12, are not uniform according to their averaging period. Sulphur oxides are a 10% over the limit but the estimation has been developed during the most crowded day in terms of cruise ships. Particulate Matter are within the acceptable limit so it is not the most worrying emission. The percentage of emissions from ships that contributes to the total emissions over Barcelona is used to be nearly the same, and it is used to be between the 45% and 55%. In figures 14 and 15 these contribution is represented for Nitrogen oxides and Particulate Mater 10 because no others were found.

Figure 14: Contributions of Nitrogen oxides emission in terms of their origin



Source: Ajuntament de Barcelona

Figure 15: Contributions of Particulate Matter 10 emission in terms of their origin



Source: Ajuntament de Barcelona

7. Conclusions

The shore side of any high voltage shore connection installation is always hard to design for cruise ship harbours due to the high power demand that this type of ships uses to need. Specially, it is hard to decide design power parameters such as frequency, voltage and the maximum amount of power it would be able to supply.

Voltage is strongly hard to decide, because big cruise ships use to have nominal voltages from 6,6 to $11kV$ A.C. That two limits are the most standardized nominal voltages for that systems according to the International Standardization Organisation (ISO), (ISO/IEC/IEEE 80005-1, 2012). Then, as it provides the mentioned Standard, high voltage shore connections shall be able to supply power with nominal voltages of 6,6 kV A.C. and/ or $11kV$ A.C. In that way, if these systems would be able to supply power with both nominal voltages, distribution systems will be more expensive and hard to design because all connection points should offer the same versatility in front of different on board power plant's nominal voltages. Otherwise, if some ships use to repeat itinerary at the same ports and have dedicated berths, other IEC voltage nominal values may be considered.

Frequency is not as hard to decide as voltage because it is narrowly limited to $50Hz$ or $60Hz$. Once again, a versatile installation would be the best option. Including frequency converters in design's final solution will provide to the system more flexibility and a wide range of cruise ships would be able to use the system. In Europe, nominal frequency is $50Hz$ and because of that, one frequency converter at least, must be installed due to $60Hz$ is the most used frequency on board for cruise ships.

As regards to power demand for hoteling services, it cannot be estimated with high accuracy. To do it, power load curves while they are berthed should be provided. But the developed models are useful to estimate the maximum power they would be able to demand at full hoteling power load. Then, design's nominal power can be estimated. The chosen model for developing daily's power curve for Barcelona's cruise piers, based on gross tonnage and corresponding to model 3, provides the highest results that will assure an acceptable design due to its oversizing. But, model 2 is the most standardized obtained model because can be used for all kind of cruise ships and its correlation factor is the highest one within delete dispersed points.

In contrast, the estimation will have higher accuracy, if model 4 is used to estimate conventional cruise ships and model 3 is used for estimating not conventional cruise ships. Not conventional cruise ships are defined in that case for the following types:

- The biggest cruise ships, with lengths over 300 meters and 125000 tonnes of gross tonnage.

- Very luxurious cruise ships with less passenger's capacity than other cruise ships with similar lengths.

In addition, to estimate real power demand and consequently improve the model a service factor must be considered. A service factor of 0,40 applied over the obtained result of integrating daily's power demand curve must be included as the final step of the model.

Checking tables 4 and 5 emission reductions as a result of using shore to ship connection instead of auxiliary engines, the conclusion is very clear. Using shore to ship connection reduces emission levels more than 90% comparing it with using auxiliary engines. In addition, the European Union is trying to make using shore to ship connection easier for all the involved parts by its recommendations and directives. In contrast, CH_4 emissions are higher producing it by power plants than by auxiliary engines. After analysing the obtained contributions from each gas over the total, CO_2 is once again the most contributing one. It is difficult and hard to regulate, strongly after the actual situation of Kyoto's protocol but some means should be developed to reduce CO_2 pollution coming from ships moreover MARPOL's actual means; (IMO Virtual Publications, 2005; The International Council for Clean Transportation, 2011; Lloyd's register, 2011); such as the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP).

It may not be possible in all type of ships because of the amount of business that depends on the maritime traffic, but it may be controlled in a more restrictive way for cruise ships. If that means would not be possible, benefits or privileges could be awarded for ship owners that will invest and develop new less-polluting systems in their fleet. Moreover, the concession of these benefits would contribute in their corporative social responsibility, increasing at the same time their cruise line image for people.

As regard to air quality, the Directive 2008/50/EC would be more complete and easy to apply if each gas and its limit values were expressed within the same averaging periods. The consideration of installing a high voltage shore connection system at Barcelona's cruise piers is completely evaluated. The current paper provides enough tools and evidences to recommend its installation and to make a conceptual design and its previous study.

References

References

Ajuntament de Barcelona, (2014). Plan to improve air quality in barcelona 2015-2018.
URL: http://ajuntament.barcelona.cat/

Barcelona's port, (2013). Barcelona cruise facilities.
URL: www.portdebarcelona.cat/en

Barcelona's port, (2013). Barcelona port traffic statics.
URL: www.portdebarcelona.cat/en

Barcelona's port, (2013). Cruise traffic prediction 2014.
URL: www.portdebarcelona.cat/en

Barcelona's port, (2014). Cruise traffic prediction 2015.
URL: www.portdebarcelona.cat/en

Barcelona's port, (2014). Cruise traffic statics 2014.
URL: www.portdebarcelona.cat/en

Barcelona's port, (2015). Cruise traffic statics 2015.
URL: www.portdebarcelona.cat/en

BOE, (2011). Real decreto 102/2011, de 28 de enero, relativo a la mejora de la calidad del aire.

BOE, (2014). Real decreto 678/2014, de 1 de agosto, por el que se modifica el real decreto 102/2011, de 28 de enero, relativo a la mejora de la calidad del aire.

Brown, Watts, Thunem, (2006). Cruise ship shore power projects - alternative maritime power (amp). Conference at Los Angeles.

Daniel J.Jacob, Darrell A. Winner, (2009). Effect of climate change on air quality. elsevier by science direct.

ENTEC UK, (2005). European commission directorate general environment - service contract on ship emissions: Assignment, abatement and market-based instruments (shore-side electricity task 2a).

ENVIRON International Corporation Seaworthy Systems, Inc., YEI Engineers, Port of San Francisco Pier 1, (2005). Final report shoreside power feasibility study for cruise ships berthed at port of san francisco.

Godish, T., Wayne T. Davis, Joshua S. Fu, (2015). Air quality fifth edition.

Green Biz, (2013). Maersk line cruises to lower shipping emissions levels.
URL: www.greenbiz.com

IMO Virtual Publications, (2005). Marpol annex vi.

ISO/IEC/IEEE 80005-1, (2012). High voltage shore connection (hvsc). Systems – General requirements.

Lloyd's register, (2011). Implementing a ship energy efficiency management plan (seemp).

L.Schrooten, I. De Vlieger, Panis, L. I., Chiffi, C., Pastori., E., (2009). Emissions of maritime transport: a reference system. Journal of Maritime Research.

Merk, O., (2013). The competitiveness of global port-cities: Synthesis report. OECD Regional Development Working.

Official Journal of the European Union, (2003). Council directive 2003/96/ec of 27 october 2003 restructuring the community framework for the taxation of energy products and electricity.

Official Journal of the European Union, (2005). Directive 2005/33/ec of the european parliament and of the council of 6 july 2005.

Official Journal of the European Union, (2006). Recommendation 2006/339/ec.

Official Journal of the European Union, (2008). Directive 2008/50/ec.

Patrick Ericsson, Ismir Fazlagic, (2008). Shore side power supply. Ph.D. thesis, Chalmers University.

Paul Polman, CEO of Unilever, (2016). Why sustainability is no longer a choice.
URL: ttp://www.livescience.com/

Quaranta, F., Fantauzzi, M., Coppola, T., Battistelli, L., (2012). The environmental impact of cruise ships in the port of naples: Analysis of the pollution level and possible solutions. Journal of Maritime Research.

Tetra Tech for the American Association of Port Authorities, (2007). Draft use of shore-side power for ocean-going vessels white paper.

The International Council for Clean Transportation, (2011). The energy efficiency design index (eedi) for new ships.