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WORK RISK MEASURES IN SEVER ENVIRONMENTS OF A SHIP

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ABSTRACT

Ships are a clear example of thermal indoor environment with characteristics changing in short intervals of time. In the engine room the conditions used to be extreme as well.

In this study, we have carried out a monitoring of air temperature and relative humidity in several locations of a merchant ship that covers the sea lane Las Palmas-Barcelona.

Subsequently, it has been determined from those indoor temperature and relative humidity data, the corresponding parameters of thermal comfort (predicted mean vote, PMV; predicted percentage of dissatisfied, PPD and acceptability, Acc) and heat stress of sever exposures in the engine room.

Key words: Work-risk measures, heat strain, thermal comfort, PMV, PPD.

INTRODUCTION

The thermal parameters of indoor environments need a suitable study, knowledge and processing in relation with the industrial safety, because high or low air temperatures and not controlled heat sources, may induce lower productivity rates, higher accidents rates and health hazards.

A clear example of thermal indoor environment with extreme characteristics changing in short intervals of time is a ship. In this study, we have carried out the

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sampling of air temperature and relative humidity in a merchant ship that covers the sea lane Las Palmas-Barcelona-Las Palmas.

In the indoor environment of a ship, it is the engine room that is important having in mind its special characteristics related with safety at work. Temperature and relative humidity data from the engine room and other locations have been analysed to obtain comfort indexes by means of new models applied to this environment.

From this analysis of real conditions, it has been possible to define limit time that a person can work without heat stress in accordance with spanish standards NTP.

METHODS

By means of Gemini® data loggers, a monitoring of air temperature and relative humidity has been carried out in a merchant vessel during the voyage Las Palmas-Barcelona and return in the winter season of 2001. The engine room together with the control room, the dinning room for officers and the bridge has been the sampling locations. At the same time, outdoor data have been also obtained for comparing purposes. More than 11,000 measurements have been collected.

As previously stated, we have paid special attention to the engine room environment. Thus, we have collected data both from the control engine room and the proper engine room.

To obtain measurements of work environments, data-loggers were located to a height near the centre of gravity of workers when they remain in the usual position of work. In those places where this position was not possible to fix, the sampling points were moved away from heat sources such as walls or air conditioning equipments at least 0.6 m, for avoiding interferences. This is the case of the engine room where several work places, those were anticipated hotter and colder and in the centre of place, have been assessed according to recommendations of INNOVA (1997).

ANALYSIS OF MONITORED VARIABLES

Because ASHRAE standards (2001) only discuss about the different comfort zones, the European standard ISO 7730 (1994) has been analysed in relation to the required conditions of indoor environments. Table 1 lists these conditions for different seasons and all practical applications.

As opposed to the real conditions in other locations, it has been obtained an average temperature in the control engine room of 19.76 ºC. This temperature is too low compared to that in the engine room, so this fact can cause both a thermal shock for workers and high-energy consumption for air conditioning.

Average relative humidity in the bridge and dinning room has reached 50%, very close to the maximum value recommended in standards (see Table 1). Whereas in the control engine room average relative humidity was 40%, in the engine room the value was 25%, in clear opposition to the rest of locations and under the minimum value of 30% recommended.

Table 1. Reference values for indoor conditions.

Applications	Summer		winter	
	Temperature (ºC)	Relative humidity (%)	Temperature (ºC)	Relative humidity (%)
All	>23	30-65	18-22	30-65

Given the influence of outdoor conditions on indoor environment, we have collected outdoor data during the monitoring period from December 2001 to February 2002. The results obtained were an average temperature of 23 ºC, with maximum values of 27 ºC and an average relative humidity of 60 %. The weather was predominantly sunny and not much cloudy.

The assessment of indoor environments is based in the study of comfort indexes, however the variables involved in the definition of such indexes must remain in the range provided by standards. For this reason, we have carried out a statistical analysis of temperature, relative humidity and enthalpy data. Results in each location are shown in Tables 2, 3 and 4.

The average temperature of the air both in the bridge and dinning room has remained about 22 ºC (see Table 3). In the engine room the average was 32.5 ºC, with peaks of 38.5 ºC. These results are out of the allowed values for hot environments and can produce different health disorders (see Figure 1).

As fast as indoor temperature increases the first psychical disorders appear such as loss or difficulties of concentration. Finally, physiological disorders as heart and circulatory system overload could yield.

According to the indications of NTP 18 (Heat stress evaluation of sever exposures) (NTP, 18) and NTP 350 (Heat stress evaluation required sweating index) (NTP, 350) standards, we got the corresponding graphics in Figures 2 and 3. They are based in human body thermal balance and they showed the maximum time that a worker could remain in sever exposures as engine rooms. The minimum time that the same worker must be at the control room to lose the accumulated heat was also calculated.

This study is refered to a standard worker with 70 kg in weight and light clothes. The Figures show that the exposition must stop when the internal temperature increases 1 ºC, because the maximum evaporation is lower than the required for the thermal balance.

Figures express the relationship between time and globe temperature because the ship ambient changes during the voyage.

Using the obtained graphics for this engine room we can affirm that the worker must be in the engine room for 17 minutes and must have a rest at the control room for at least 10 minutes in order to get the suitable heat release.

Table 2. Statistical analysis of temperature data collected in different sampling locations of the ship.

Temperature T (ºC)	Dinning room	Bridge	Engine room	Control engine room
Average	22.05	21.41	32.50	19.76
Standard deviation	1.76	2.14	2.83	1.33
Maximum	25.40	26.90	38.50	27.30
Minimum	17.10	16.20	25.40	17.40

Table 3. Statistical analysis of relative humidity data collected in different monitoring locations of the ship.

Relative humidity, RH (%)	Dinning room	Bridge	Engine room	Control engine room
Average	50.66	49.66	24.90	41.17
Standard deviation	8.19	8.67	4.15	6.58
Maximum	69.90	73.80	33.90	70.50
Minimum	28.10	21.90	16.20	30.30

Table 4. Statistical analysis of enthalpy data collected in different sampling locations of the ship.

Enthalpy, h (kJ/kg)	Dinning room	Bridge	Engine room	Control engine room
Average	43.03	41.58	52.20	34.58
Standard deviation	5.24	6.56	6.47	2.79
Maximum	54.76	52.07	66.39	66.39
Minimum	31.11	1.00	35.37	35.37

Figure 1: Influence of temperature on heat illness.

Temperature	Biologic response	Heat disorders
20 ºC	Comfortable	Full capacity
↓	Discomfort Irritability Concentration difficulties Decrease in intellectual capacity	Psychical disorders
↓	Increase in work mistakes Decrease in handiness More accidents	Psychical and physiological disorders
↓	Decrease in efficiency of heavy works Disturbance of metabolism Cardiac-circulatory system overload Heavy fatigue	Physiological disorders
35-40ºC	Maximum temperature bearable	

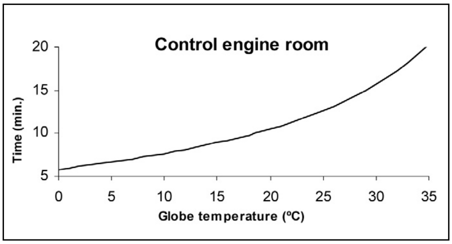

Figure 2. Minimum time that mus be elapsed in the control engine room.

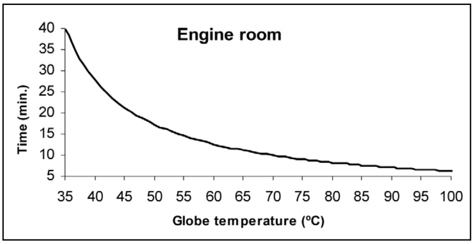

Figure 3. Máximum time that must be elapsed in the engine room.

STUDY OF COMFORT CONDITIONS

To keep thermal comfort and avoid disorders two conditions must be fulfilled. The first is that the combination of skin and deep body core temperatures leads to a neutral feeling of comfort. The second involves the energy balance between the body and the environment. In this sense, the total metabolic heat produced by the body should be equal to the heat loss from the body.

The comfort equation developed by P. O. Fanger [3] relates physical parameters that can be measured with the neutral thermal feeling experimented by a "typical" person:

$$M - W = H + E_c + C_{res} + E_{res} \tag{1}$$

M = metabolic rate, W/m^2. It is the rate of chemical energy transformation from aerobic and anaerobic activities, in heat and work.

W = rate of mechanical work performed, W/m^2.

H = heat exchange from the skin by convection, conduction and radiation, W/m^2.

E = evaporative heat exchange, W/m^2.

E_C = evaporative heat exchange through the skin, in conditions of neutral thermal feeling, W/m^2.

C_{res} = respiratory heat loss by convection, W/m^2.

E_{res} = respiratory heat loss by evaporation, W/m^2.

Through measurement of physical parameters, the comfort equation provides an operative tool whereupon it can be assessed under what conditions the thermal comfort in an occupied space is achievable. The thermal comfort can be quantified through indexes defined in standard ISO 7730 (Fanger, 1970). The Predicted Mean Vote (PMV) is derived from the heat balance before mentioned and provides an indication of the thermal sensation by means of a scale of 7 points, from -3 (cold sensation) to +3 (hot sensation), where 0 means a neutral thermal sensation. Another comfort index is the Predicted Percentage of Dissatisfied (PPD) that provides information on thermal sensation by predicting the percentage of people likely to feel too hot or too cold in a given environment. PMV values of -3, -2, +2 and +3, means thermal discomfort in the PPD index. Both indexes are influenced by physical activity and clothing. The physical activity is quantified through the metabolic rate. The human body maintains a minimum rate of heat production at about 60 W during sleeping. The metabolic rate is often expressed in Met, which means a heat production of 58 W/m^2 of body surface. On the other hand, clothing acts as an insulation reducing the heat loss from the body. A magnitude called Clo is normally used to quantify the insulation of the different clothes. In terms of thermal resistance 1 Clo is equivalent to 0.155 $m^2\,{}^{o}C/W$.

In this study, we have used the PMV models developed by the Institute for Environmental Research Kansas State University (ASHRAE, 1985) for the assessment of the thermal comfort conditions in indoor environments. The expression of the model is the following:

$$PMV = at + bP_v - c \tag{2}$$

Where t is the temperature and P_v is the vapour partial pressure. Right constants a, b and c must be used to take into account sex and time of exposure to the indoor environment. Such constants have been adapted to the existing conditions in the studied environments by means of a thermal comfort data-logger 1221 from Innova. Values of 1.2 Met and 1 Clo were assumed for calculations.

PPD has been also studied for the same environment. The index has been defined by means the following equation, taking into account the PMV values previously obtained:

$$PPD = 100 - 95 \cdot e^{-\left(0{,}03353\, PMV^4 + 0{,}2179\, PMV^2\right)} \tag{3}$$

Temperature and relative humidity values collected in the ship have been introduced in the models just detailed and corresponding PMV and PPD values has been calculated for each indoor location. Tables 5 and 6 show the statistical analysis of results.

In order to make comparisons, the thermal acceptability (Acc) has been also calculated. This new index, introduced by Fanger (1970), has been used by Simonson et al. (2001) to assess indoor environments as a result of their adaptation to any kind of thermal conditions but with loss of accuracy. The index is related with enthalpy through the following equation:

$$A_{cc} = a \cdot h + b \tag{4}$$

Where a and b are empirical coefficients whose values for clean air are -0.033 and 1.662 respectively. Table 7 shows the average acceptability in the engine room.

Once averages and standard deviations have been assessed, it has been quantified what values have been broken the standards according with ASHRAE. Such specifications set a PMV range that goes from -0.5 to +0.5 as adequate. This interval is equivalent to a PPD lower than 10 %.

To make the interpretation of results easier, Figures 4 to 11 show the relative frequency graphs of PMV. The cumulative PPD curve has been also plotted.

Table 5. Statistical analysis of calculated PMV values in different locations of the ship.

PMV	Dinning room	Bridge	Engine room	Control engine room
Aerage	0.21	0.19	2.15	0.52
Standard deviation	0.51	0.48	1.01	0.37
Maximum	1.74	2.13	3.75	1.77
Minimum	-0.96	-0.91	1.54	-0.90

Table 6. Statistical analysis of calculated PPD values in different locations of the ship.

PPD	Dinning room	Bridge	Engine room	Control engine room
Average	11.31	8.80	76.61	13.54
Standard deviation	10.51	12.8	34.88	5.20
Maximum	64.13	82.60	99.99	65.92
Minimum	5.00	0.00	53.06	5.00

Table 7. Average acceptability in the engine room.

Acc	Dinning room	Bridge	Engine room	Control engine room
Average	0.23	0.30	-0.05	0.52

Bridge and dinning room

Figures 10 and 11 show a cumulative PPD in the bridge and dinning room close to the neutral thermal conditions. The last one is the location more comfortable, followed by the bridge; since 90% and 78% of collected data are included in the 10 % of PPD, according with the ASHRAE standard. These results mean that it is not possible the energy optimisation of indoor environment, because outdoor and indoor air temperatures maintain similar values. Nevertheless, in these environments relative humidity usually exceeds 55% established by ASHRAE and ISO standards. For this reason, it would be advisable the use of dehumidifiers for protecting both occupiers and electrical devices of the bridge.

Engine room

The most extreme conditions have been found in the engine room (see Figures 4 and 8). PMV and PPD values of 2.15 and 76.61 %, has been obtained. These extreme values together with the fact that nearly all calculated PPD data exceed 10 % show that in this location the thermal sensation is very hot.

From Simonson's studies [8] can be deduced that acceptability is better with a lower enthalpy. He has established the value of 50 kJ/kg as the upper limit for enthalpy. Above this value the air perception is unbearable, independently of the indoor air quality. In our case, the enthalpy value in the engine room exceeds 52 kJ/kg and thus the calculated acceptability has been -0.05.

Values of relative humidity are low because high outdoor temperature. These conditions may cause hyperthermia, vasodilatation, sweat glands activation, increase of peripheral circulation and electrolytic changes of sweat by loss of salt content. As a possible solution to this problem, an increase in ventilation rates may achieve some decrease in temperature.

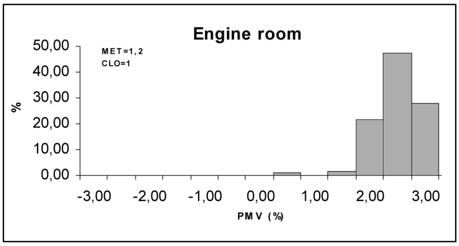

Figure 4. Relative frequency of PMV in the engine room.

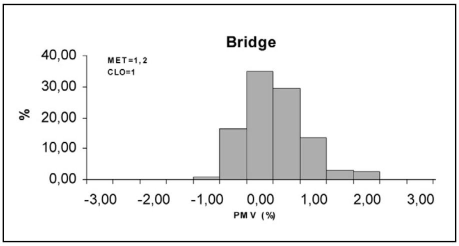

Figure 5. Relative frequency of PMV in the bridge.

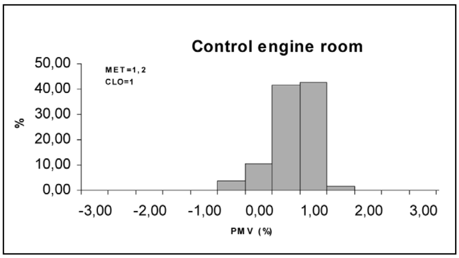

Figure 6. Relative frequency of PMV in the control engine room.

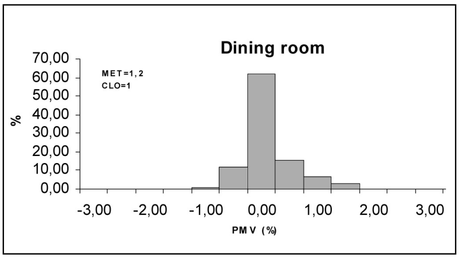

Figure 7. Relative frequency of PMV in the dinning room.

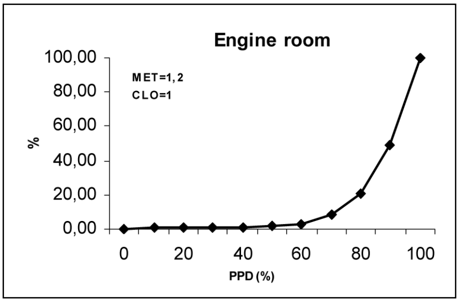

Figure 8. Cumulative frequency of PPD in the engine room.

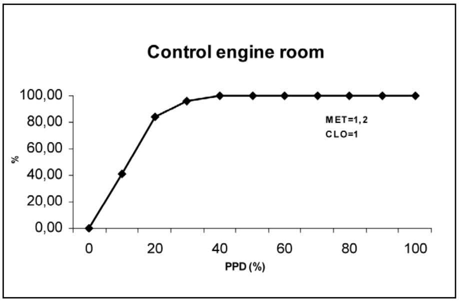

Figure 9. Cumulative frequency of PPD in the control engine room.

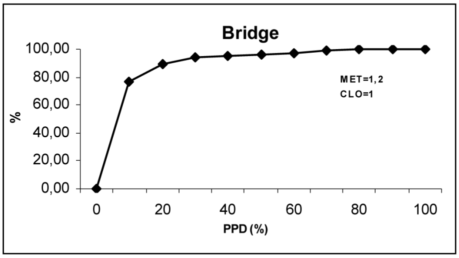

Figure 10. Cumulative frequency of PPD in the bridge.

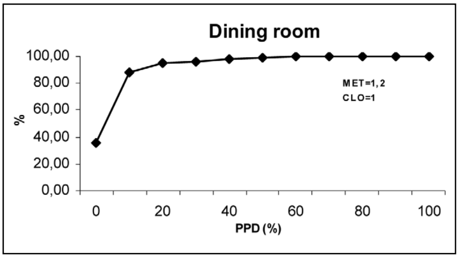

Figure 11. Cumulative frequency of PPD in the dinning room.

Control engine room

In this location the PMV is close to 0.5, the optimum condition for energy saving, the average PPD is 13 % and 40% of calculated PPD data are within 10 % fixed in standards (see Figures 6 and 9). These results lead to a limit condition in the control engine room. Besides, the average temperature of 19.76 ºC and the average relative humidity of 24.9% (lower than the minimum reference value of 30 % from ISO 7730 [3]) are too low which means a high-energy consumption in air conditioning.

To get an energy saving, the temperature should be higher than 20 ºC as in accordance to the air acceptability criteria, to maintain the same PPD, the enthalpy must be the same as well. For this reason, a temperature increase of 1ºC leads a relative humidity decrease of 5% and the lower limit of 30% already mentioned would not be fulfilled. All these facts lead to set the existing temperature conditions as optimum for the existing relative humidity.

A possible improvement may be to increase the air renovations with outdoors, to cause an increase of both relative humidity and temperature towards values more suitable.

Another solution to correct the low relative humidity may be to avoid the possible dehumidification of conditioning air in the chiller by means air conditioning unit to be replaced by another one with higher surface area of heat exchange that causes a higher external surface temperature for the same heat rate.

CONCLUSIONS

- Ships show very different thermal environments that must be studied with greater depth.
- Options of energy saving or thermal comfort improving in the bridge and the dinning room are very limited.
- The engine room shows air conditions out of any recommendations from standards, so it is suggested an increase in ventilation for taking preventive measures against work risks.
- The control engine room shows limit conditions of thermal comfort with temperature values too low that lead to an excessive energy consumption. As the outdoor air conditions are suitable, an increase of renovations with outdoor air can be proposed.
- Taking into account our results it would be necessary to take the following work risk-preventing measures:
  — Drinking water. Sources of drinking water must be available close to work locations and workers must be informed about the necessity of drinking frequently.
  — Acclimatization. Workers starting new or going back to work require an exposure time for achieving acclimatization.
  — Metabolic heat. Adjusting length and frequency of breaks and work periods, and work rates may be reduced the metabolic heat release. If it is possible works must be scheduled in time of less heat. Work periods into engine room must not be higher than twenty seven minutes and, after it, worker must be about ten minutes in the control room.
  — Workers must be kept under constant watch by a trained colleague for detecting any symptom of heat strain.

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PREVENCIÓN DE RIESGOS EN AMBIENTES EXTREMOS DE UN BUQUE

Resumen

Los buques son un claro ejemplo de ambiente interior cuyas características varían en breves intervalos de tiempo. En este trabajo se han muestreado las variables de temperatura y humedad relativa en diversas zonas de un buque que realiza periódicamente la misma ruta.

Una vez analizadas las condiciones de temperatura y humedad relativa, se han definido los índices de confort térmico por medio de modelos definidos por la Ashrae, prestando especial atención a la sala de máquinas, dadas sus características especiales en torno a la seguridad laboral.

También se han calculado los períodos de trabajo en la sala de máquinas y descanso en la sala de control para prevenir la aparición de los síntomas de estrés térmico.

MÉTODOS

Las condiciones de temperatura y humedad relativa han sido muestreadas por medio de Gemini data loggers durante una ruta típica. Las zonas analizadas han sido; la sala de máquinas, sala de control, puente, comedor de oficiales y ambiente exterior. En total, se han recogido más de 11000 mediciones.

Para que las condiciones muestreadas sean lo más representativas posible, dichos data loggers se han ubicado cerca del centro de gravedad de los trabajadores pero alejados de fuentes térmicas como paredes, y equipos de acondicionamiento de aire.

Los resultados obtenidos se han comparado con las indicaciones de la normativa ISO 7730 en función de sus indicaciones, las cuales se han resumido en la Tabla 1.

Tabla 1. Valores de referencia para las condiciones interiores.

Verano		Invierno	
Temperatura (ºC)	Humedad relativa (%)	Temperatura (ºC)	Humedad relativa (%)
>23	30-65	18-22	30-65

RESULTADOS

Estudio de las variables termodinámicas

Los resultados se muestran en las tablas 2 y 3.

La temperatura promedio del aire en el puente y en el comedor de oficiales ha permanecido en torno a 22ºC. En la sala de máquinas el valor promedio ha sido de

Temperatura T (ºC)	Comedor	Puente	Sala de máquinas	Sala de control
Promedio	22,05	21,41	32,50	19,76
Desviación típica	1,76	2,14	2,83	1,33
Máximo	25,40	26,90	38,50	27,30
Mínimo	17,10	16,20	25,40	17,40

Tabla 2. Análisis estadístico de la temperatura muestreada en las diferentes zonas del buque.

Humedad relativa (%)	Comedor	Puente	Sala de máquinas	Sala de control
Promedio	50,66	49,66	24,90	41,17
Desviación típica	8,19	8,67	4,15	6,58
Máximo	69,90	73,80	33,90	70,50
Mínimo	28,10	21,90	16,20	30,30

Tabla 3. Análisis estadístico de la humedad relativa muestreada en las diferentes zonas del buque.

32,5 ºC con picos de hasta 38,5 ºC. Estos valores superan los valores permitidos para ambientes térmicos de forma que se puede originar problemas de salud. A medida que aumenta la temperatura interior aparecerán los primero signos de desordenes térmicos como la pérdida o dificultad de concentración, hasta llegar a originar la sobrecarga del sistema circulatorio.

A pesar de que en la mayoría de las zonas del buque se respetan las indicaciones de la normativa, en la sala de máquinas la humedad relativa promedio es de 25 ºC. Dicho valor es claramente inferior al valor mínimo recomendado.

Estudio de los índices del confort

La Ecuación de Confort nos proporciona una herramienta operativa con la cual, midiendo unos parámetros físicos, podemos evaluar bajo que condiciones podemos ofertar comodidad térmica en un espacio habitado. Dicha comodidad puede ser definida mediante el índice PMV de Voto Medio Previsto (Predicted Mean Vote). El índice PMV predice el valor medio de la sensación subjetiva de un grupo de personas en un ambiente determinado mediante un rango de sensación térmica de 7 puntos, desde -3 (frío) a +3 (caliente), donde el 0 representa una sensación térmica neutra.

Para predecir cuánta gente está insatisfecha en un ambiente térmico determinado, se ha introducido el índice de Porcentaje de Personas Insatisfechas PPD (Predicted Percentage of Dissatisfied). En el índice PPD la gente que vota - 3, - 2, +2, +3 en la escala PMV se considera térmicamente insatisfecha.

Para el estudio de las condiciones de confort térmico existente en dichos ambientes interiores, se han empleado los modelos de PMV desarrollados por el Instituto para la Investigación Ambiental de la Universidad del Estado de Kansas. Su estructura es la siguiente:

$$PMV = at + bP_v - c \qquad (2)$$

También se han definido el porcentaje de insatisfechos ante ese mismo ambiente de estudio. Este índice se ha definido por medio de la ecuación 2, determinada a partir de los valores de PMV anteriormente obtenidos.

$$PPD = 100 - 95 \cdot e^{-\left(0,03353\,PMV^4 + 0,2179\,PMV^2\right)} \qquad (3)$$

Las condiciones de temperatura y humedad relativa obtenidas han sido introducidas en los modelos creados, de forma que se han determinado los valores de PMV correspondientes.

Los resultados han mostrado para la sala de máquinas unos valores de 2,15 de PMV y la mayoría de los valores superan el 10 % de insatisfechos, por lo que la sensación térmica es muy calurosa.

En la sala de control el 40% de las mediciones están dentro del 10% de PPD y el PMV promedio ha sido de 0,5, por lo que se puede decir que dicho ambiente se encuentran optimizados térmicamente. A pesar de tener esa temperatura, los valores de humedad relativa están por debajo del límite inferior fijado por la normativa.

En función de las normativas NTP 18 y 350 se han determinado los gráficos que definen el tiempo máximo de estancia en la sala de máquinas y mínimo necesario en la sala de control para poder perder el calor acumulado y evitar posibles riesgos laborales. En concreto, se recomiendan períodos de trabajo de 17 minutos y descansos, en la sala de control, de 10 minutos.

CONCLUSIONES

Los buques presentan ambientes térmicos muy variados que deben ser estudiados con mayor profundidad.

La sala de máquinas presenta unas condiciones ambientales fuera de cualquier normativa, por lo que se sugiere un aumento de la ventilación para la prevención de posibles riesgos laborales.

La sala de control presenta una situación límite de confort térmico, pero a una temperatura demasiado baja, por lo que se origina un consumo energético excesivamente elevado. Se ha propuesto un aumento del número de renovaciones con el ambiente exterior, dado que éste presenta unas condiciones más adecuadas.

Es necesario acatar una serie de medidas para la prevención de riesgos laborales ante ambientes tan extremos:

Agua potable: debe existir una fuente adecuada de agua potable cerca del lugar de trabajo, y los trabajadores deben estar informados de la necesidad de ingerir agua con frecuencia.

Aclimatación: aquellos trabajadores nuevos o aquellos recién incorporados (por baja o vacaciones) o aquellos que estén asignados a trabajos más ligeros, deben tener un período de aclimatación previo antes de incorporarse definitivamente a pleno trabajo. Este es el caso del embarque de personal procedente de largos periodos de descanso, lo cual es un suceso muy habitual.

Calor metabólico: puede reducirse el calor interno generado mediante ajustes en la duración del período de trabajo, la frecuencia y duración de los intervalos de descanso, el ritmo del trabajo y la mecanización del trabajo. El estudio ha mostrado períodos de trabajo en la sala de máquinas de 17 minutos y periodos de descanso en la sala de control de 10 minutos.

Vigilancia por un compañero: los trabajadores deben ser observados por un supervisor entrenado que pueda detectar a tiempo cualquier síntoma de sobrecarga térmica.