T E S T U D O

Introduction to Temperature and Environmental Control (TEC) Systems

A Study Guide for Testudo Level 1 Certification

OVERVIEW

This guide offers a range of information on spacecraft environmental systems that will prepare students for the Testudo TEC Certification Exam (Level 1). TEC certified engineers and technicians are authorized to install, repair, and provide maintenance for environmental and temperature systems on all Testudo vessels.

CONTENTS

This guide is organized into five units and culminates in a quick start checklist a TEC technician can use when creating spaceworthy environments.

Unit One

INTRODUCTION TO ENVIRONMENTAL SYSTEMS

GOALS

The primary goal of a Temperature and Environmental Control (TEC) system within a spacefaring vessel is to maintain the safety of the crew and cargo aboard. Space is a cold, airless and hostile environment indifferent to the needs of the life forms within it. Spacefarers are constantly under threat of losing oxygen, being poisoned by carbon monoxide, or merely freezing to death, among dozens of other potential dangers. Safety within such an environment requires constant maintenance even in the best of circumstances.

A secondary goal of a functioning TEC system is comfort. With the proper knowledge and skill set, a Testudo Temperature and Environmental Control technician (TEC tech) can produce an oxygen rich, temperate environment not dissimilar from those found planetside. Testudo manufactures a line of spacecraft for use in several industries, from tourism to mining to diplomacy, and many of these industries rely on long haul work and travel. Producing a comfortable environment within these craft can be the difference between a successful and unsuccessful journey.

STRUCTURE

The structure of an environment in microgravity can be broadly divided into two categories: 1) temperature and 2) air pressure mixture. The former is a measure of how hot or cold a given environment becomes, as well as the dynamics of that environment as heat is transferred throughout the ship. The latter is the quantity and composition of environmental gasses (usually Oxygen, Nitrogen and Carbon Dioxide) held within a cabin or a network of cabins on a vessel, as well as the dynamics of those gasses as they are transferred throughout the ship.

In short, the TEC tech is responsible for both keeping the ship warm enough to be habitable outside a pressure suit and filled with breathable air.

Bear in mind that in both cases the technician is dealing with a dynamic gas system. This means that rather than remaining still, the environment is constantly expanding to fill a cabin. When such a cabin is not available, the environment will rush out through any exposed airway, be it a door, gap in the ship's hull, or even through the crack in a wall. Therefore, your responsibility as a TEC tech includes not only producing a safe environment, but holding that environment within a ship structure.

TEMPERATURE AND CONTENTS OF SAFE ENVIRONMENTAL MIXTURES

A well designed TEC system should hold Oxygen levels within any pressurized cabin above 20 kilopascals (kPa). While it is possible to survive an O2 range below 20kPa, working in low pressure environments can quickly result in fatigue, issues with memory and decision-making, loss of consciousness, or even death. Additionally, while O2 levels above 20kPa are considered safe to breathe, they present a significant flammability risk. For these reasons, an O2 level between 20 and 23kPa is considered ideal.

If a ship cabin dips below 16kPa, technicians and crew should immediately seek safety within a pressurized cabin. Humans working within Oxygen compositions below 16kPa will begin to experience the symptoms of Hypoxia (see below), which are dangerous and eventually fatal.

Finally, it cannot be overstated that Oxygen pressures approaching 0kPa are uninhabitable. Occupying such an environment outside a pressure suit leads to immediate asphyxiation.

Nitrogen (N2) and Carbon Dioxide (CO2) compositions are only slightly less vital than Oxygen compositions within an environmental system. Environmental mixtures exceeding 1kPa CO2 can lead to Carbon Dioxide poisoning. CO2 mixtures approaching 0kPa are considered ideal. Nitrogen in an environment is not poisonous to humans, nor is it vital to creating a breathable environment. That said, spacefarers conditioned to planetside atmospheres are best suited to an environment with Nitrogen levels between 40 and 70 kPa.

High Nitrogen content in a cabin has the danger of displacing oxygen. If Nitrogen content in a cabin climbs above 180kPa then Oxygen levels may begin to fall. If a TEC tech discovers an unexplained decrease in Oxygen pressures, it could be due to overhigh Nitrogen content in the environmental mixture.

PRESSURE SUITS

A pressure suit is an insulated and fully sealed garment that protects the wearer from the external environment. As a TEC tech, it is best to think about a pressure suit as a microclimate: a hermetically sealed environment with all the same properties of a sealed cabin, only enclosed within a smaller space.

In this way, the TEC tech should seek to achieve the same spaceworthy environmental mixture and temperature within a pressure suit as they would build outside of one. O2 levels should remain between 20 and 23kPa when possible, and never drop below 16kPa. CO2 levels should remain below 1kPa. N2 is safe to breathe, but due to mobility concerns any non-O2 gases are considered undesirable in a pressure suit.

While the goals of maintaining an environment within a pressure suit are similar to goals of maintaining one outside of a pressure suit, the risks are much higher. Because the space is smaller, CO2 builds up faster, and O2 is more quickly consumed by the occupant. When working within a pressure suit, the TEC tech should maintain a clear path to a spaceworthy cabin in which they can remove their helmet and replenish the microclimate with clean, warm, breathable air before returning to work.

HYPOXIA

Hypoxia is a medical condition caused by a lack of Oxygen flowing to tissues within the body. It is an unfortunately common and very dangerous condition which begins to develop when working within low Oxygen environments. The symptoms of Hypoxia are extremely subtle and often slow to onset, and thus a TEC tech should be constantly vigilant to recognize them when they appear.

The most common symptoms of hypoxia are numbness and discoloration within the extremities, nausea, stomach bloating, bubbling saliva, dizziness, headache and trouble sleeping. If the TEC tech or crew begins to experience any of these symptoms, they should ensure that their environment meets all the above standards of space safety, and commit to a period of rest in a high oxygen environment.

Unit Two

HOLDING AN ENVIRONMENT IN VACUUM

THE PRIMARY CABIN

Before a TEC tech can begin to build a spaceworthy environment, they must ensure that the ship structure can hold it. This means that the hull should be free from holes, cracks, and any other gaps to the vacuum of space through which the environment will leak.

The best practice for building such an environment is to start with the smallest possible area in range of an air pump system. This is called the **Primary Cabin**. Securing a safe primary cabin while in vacuum is a multi-step process.

First, the Primary Cabin on the pump side of the air system should be sealed off from other cabins with pressure doors (see figure 1a).

Next, while safely housed within a pressure suit, the TEC tech should seal up any obvious holes in the floor or walls of the Primary Cabin with a hull patch or full repair.

Finally, any cracked or otherwise damaged walls and floors should be sealed or rebuilt (see figure 1b).

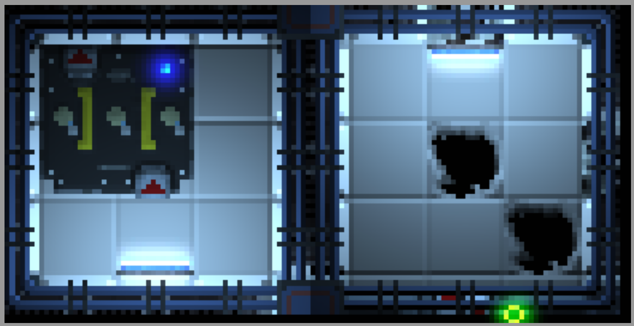

Figure 1a: Primary Cabin (right) with damaged floors and walls

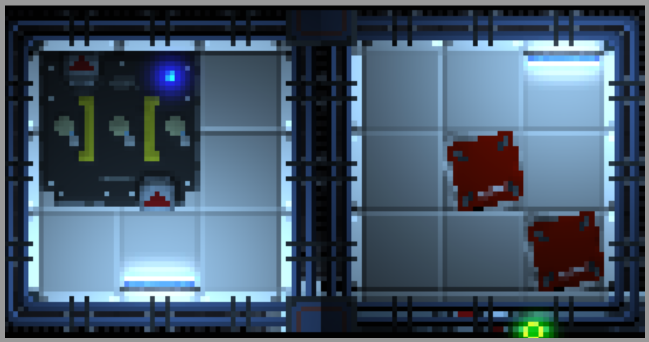

Figure 1b: Primary Cabin repaired with hull patches and re-installed walls

THE INTEGRITY TEST

Once the Primary Cabin appears to be fully sealed, the TEC tech can run a brief **Integrity Test**. This is done by flooding the Primary Cabin with an air mixture, or “pressurizing” it, and then checking for any signs of leaks. While safely housed within a pressure suit, the TEC tech can pressurize the Primary Cabin, either by turning on an air pump into the room (see figure 2) or briefly opening a door to a fully pressurized cabin.

As the Primary Cabin fills with air, a faint white gas becomes visible. This is the environmental mixture coming from the pumps or the pressurized cabin. After 3-5 seconds, the TEC tech should turn off the air pump or close the door. If the Primary Cabin is fully sealed, the pressure mixture within the cabin (O2 and N2) should remain relatively static. If instruments read a drop in pressure, or if there is visible white gas escaping through the hull, there is a leak in the cabin. Even the smallest evidence of leakage suggests that the Primary Cabin is fully compromised and should be addressed before the Primary Cabin can be deemed spaceworthy.

Once the Primary Cabin is established it can become a base of operations from which the TEC tech can pressurize adjacent cabins. While it is safe to work outside of an environmental suit in the Primary Cabin, the TEC tech should be aware that the cabin can lose pressure quickly by leaking into unpressurized nearby cabins. For this reason, it is best practice to remain working within a pressure suit until there are at least two safe cabins between the TEC tech and the safely pressurized Primary Cabin.

Unit Three

INSTALLATION AND MAINTENANCE OF AIR PUMPS

An air pump is any mechanical device that converts a liquid agent (usually O2 and/or N2) into a breathable gas and then distributes it throughout a cabin or network of cabins. While there are many makes and models of air pumps, most of which operate under the same principles, the form factor of air pumps vary. The instructions within this guide and TEC tech course of study is based on Testudo pumps and those manufactured by our partner builders at Kang Industrial. Applying these principles on non-Testudo equipment can result in forfeiture of licenses and additional Ogiso reprisal up to and including the seizure of ship assets.

STRUCTURE

A standard air pump is wall mounted and has two parts: 1) a canister intake housing and 2) a ventilation housing. These two systems are meant to be mounted on either side of a wall, with the vent side pointed into a cabin into which the canister side pumps clean and breathable air (see figure 2). It is possible, then, that the canister side is placed within a cabin that is not spaceworthy, while the vent side is in a spaceworthy cabin. If this is the case, the TEC tech should wear a pressure suit while installing and providing maintenance within such cabins.

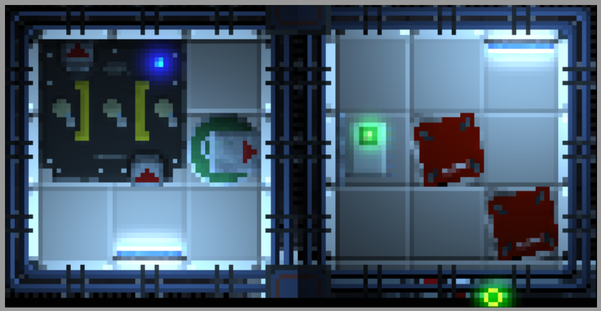

Figure 2: an installed air pump with the canister intake (left side) and ventilation housing (right cabin). A charged battery (left cabin) and conduit loop powers the system (see green light)

INSTALLATION

To install an air pump, a TEC tech should locate a wall within the ship where the canister side can be accessed by the TEC tech and the vent can pump air into the relevant cabin. Using a drill, hand torch, or similar mounting equipment, the tech should mount the center equipment housings on the wall with the canister intake on one side and a vent on the other.

Once the pump is mounted, power can be run to the center housing with any standard conduit cables that are receiving electric power. If the pump is powered and operable, the indicator light on the pump-side of the machine should turn green (see figure 2).

Once an air pump is installed, powered, and operable, gas canisters can be installed on the intake side. To create a breathable environment, a TEC tech should pump both O2 and N2 into the relevant cabin or network of cabins. To install a canister, merely place it on the intake side of the pump and ensure the nozzle is securely fastened to the housing.

SETTINGS

Standard air pumps have a control panel with a range of settings that can be accessed on close inspection of the machine (see figure 3). At a minimum, a pump has an on/off switch, as well as an “auto” function. Turning the pump “on” will pump gas at a constant rate, while turning it “off” will stop the pump completely.

The “auto” function on a pump will use an alarm/sensor device to determine when to start and stop pumping air (see Wiring Environmental Devices...below for installation instructions.) If a pump is not wired to a sensing device but is set to “auto”, it defaults to “off.”

Figure 3: the settings panel on a standard air pump. Signal wiring can be accessed by unscrewing the panel.

Additionally, some air pumps have a “reverse” function on the control panel. This switches the pump so that it is removing gas from a room rather than pumping gas into it. While this is a useful function for creating vacuum in airlocks for safety purposes, approach this setting with caution as it can very quickly remove all the breathable gas within a cabin or network of cabins.

Unit Four

INSTALLATION AND MAINTENANCE OF HEATING AND COOLING SYSTEMS

In addition to pressurizing a cabin or network of cabins, a TEC tech is responsible for stabilizing and then controlling temperature within a vessel. This is done through the installation of heating and cooling units that are wired to sensing devices and alarms installed throughout the ship.

Because space is naturally very cold, heating is an integral part of any environmental control systems. That said, rooms exposed to sunlight, or those with high energy equipment such as reactors, batteries, and terminals are capable of generating a tremendous amount of heat, and cooling such rooms quickly becomes a vital factor in ensuring both the safety and the comfort of the crew. A working TEC tech should keep their eye on their instruments at all times, as temperature can change suddenly and without warning within unstable vessels.

A safe cabin temperature within a space vessel is between 290 and 300 degrees Kelvin. Temperatures dropping below 290 puts the crew at risk of hypothermia, while temperatures above 300 degrees Kelvin risks heat exhaustion and hyperthermia. The TEC tech, therefore, is responsible for installing an integrated system of heating units, cooling units, and thermostats that keep the temperature of the vessel within this safe range.

HEATING UNITS

Standard heating units take in electricity and then convert it to energy that is held within external elements that radiate warmth into a cabin or network of cabins. Heating units, therefore, are internal mechanisms operating under relatively simple principles similar to those found planetside.

To install a heating unit, find a stable wall within the ship with functioning electrical conduits. Mount the flat socket-side of the unit to the wall with the boxed housings facing out into the cabin (see figure 4). Once installed, an operable heating unit will activate a green indicator light on the coil side of the structure.

Figure 4: an installed heating unit with boxed housing (left) facing into the cabin

COOLING UNITS

Cooling units are slightly more complex than heating units because their components are installed on both the interior and exterior of a space vessel. A standard cooling unit consists of an internal air conditioner connected to a set of radiator panels on the external hull of the ship. While the air conditioner tends to be small, the external radiator takes up a significant amount of space, so form factor is a major consideration during installation.

To install a cooling unit, find a stable wall within the ship with functioning electrical conduits. Mount the air conditioner side of the unit to the wall and ensure that there is enough external space to host the radiator panels (see figure 5.) Once installed and powered, an operable cooling unit will activate a green indicator light on the air conditioner.

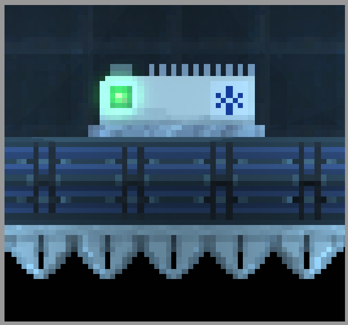

Figure 5: an installed cooling unit with internal air conditioner (top) and external radiator panels (bottom)

PANEL CONTROLS

Like air pumps, heating and cooling units have a control panel with a range of settings that can be accessed on close inspection of the machine. At a minimum, heating and cooling units have an on/off switch, as well as an "auto" function. Turning the unit to "on" will run the unit at a constant rate, while turning it "off" will stop it completely. The "auto" function on a heating or cooling unit will use a thermostat to determine when to turn on and off (see Wiring Environmental Devices...below for installation instructions.) If a heating or cooling unit set to "auto" is not wired to a sensing device, it defaults to "off."

Unit Five

WIRING ENVIRONMENTAL DEVICES TO ALARMS AND SENSORS

INPUT SIGNAL PANEL ACCESS

Air pumps, heating units, and cooling units can all be wired to sensors and alarms within a vessel for automation as well as notifications via the captain's PDA. While it is possible to create a spaceworthy environment without these so-called "smart" systems, it is incredibly time consuming and tedious. For that reason, in almost every case the TEC tech is responsible for installing a sensor system.

Air pumps, heating units, and cooling units all have settings panels with power toggles and other basic user functions (see figure 3 above). More advanced functionality can be achieved by removing the settings panel to access the signal wiring. Once the panel is removed, the TEC will see numbered input signal nodes (see figure 4). Each node can be connected to an automation device on the ship such as a pressure sensor for air pumps or a thermostat for heating and cooling units.

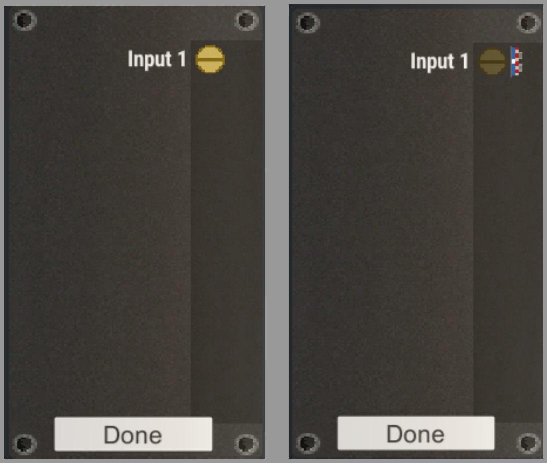

Figure 4a and 4b: input signal panel disconnected (right) and connected to a standard N2 pressure alarm (left)

INPUT SIGNAL CONNECTION

Connecting environmental units to these automation devices allows the ship crew to use the auto function on their control panel so that ship systems will self-regulate the environment with minimal effort from the captain and crew. Wiring an air pump to pressure alarms also serves as a safety precaution, as alarms will chime when environments reach unsafe levels for human habitation.

To connect a device to its relevant sensor or alarm, choose an input node and then draw the input signal to the device on the ship. A disconnected signal will render as a static blue line while a live connection will show a jagged dynamic line (see figures 5a and 5b). Among other wiring possibilities, standard air pumps can be wired to either Nitrogen or Oxygen automated pressure alarms while heating and cooling sensors can be wired to thermostats.

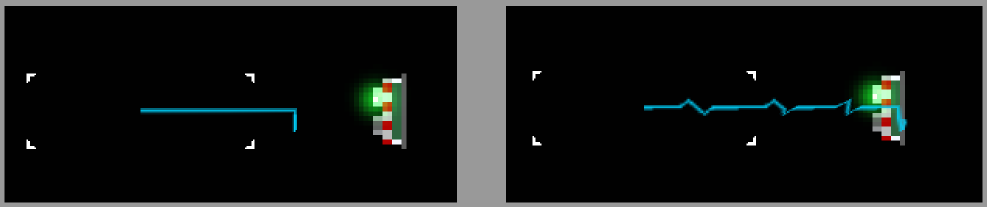

Figure 5a and 5b: disconnected input signal (left) and connected input signal (right) running from standard air pump to an Oxygen pressure alarm.

To avoid failed automation, sensing devices should be in the same cabin as the device they are wired to. If a heating unit in the galley, for example, is wired to a thermostat in an airlock, the unit will automatically begin generating heat when the airlock opens and the temperature drops, causing the galley to become massively overheated.

The same principle can be applied to air pumps, especially with respect to O2. For that reason, the TEC tech should always be aware of how a ship system is wired to avoid catastrophic failure of the environmental system.

Addendum

A CHECKLIST FOR CREATING SPACEWORTHY ENVIRONMENTS

TECHNICIAN

- ❏ TEC tech is wearing a pressure suit or an EVA suit
- ❏ O2 levels in the pressure suit are above 20kPa
- ❏ CO2 levels in the pressure suit are below 1kPa
- ❏ Temperature in the suit is between 290 and 300 degrees Kelvin
- ❏ TEC tech has a quick and safe route back to a pressurized cabin
- ❏ TEC tech has permission and ability to open all intervening airlock doors
- ❏ TEC tech is carrying installation equipment (hand drill, crowbar, canisters, etc.)
- ❏ All airlocks are closed

PRIMARY CABIN

- ❏ TEC tech designates the first cabin to pressurize as the Primary Cabin (PC). This should usually be the smallest cabin.
- ❏ Entrance and exit to the Primary Cabin (PC) are sealed with closed and powered airlock door/s
- ❏ There are no missing or damaged floors in PC, including those beneath previously installed equipment
- ❏ There are no missing or damaged walls in PC, including those beneath previously installed equipment
- ❏ TEC tech has run an Integrity Test by flooding the PC with environmental gasses and has found that it can hold them with pressure stability
- ❏ The PC has an air pump installed on a wall
- ❏ If possible, there is a clear path of entrance and egress from the PC to a safe, pressurized cabin, likely on another vessel

AIR PUMP

- ❏ The vent side of the air pump is pointed into the PC
- ❏ The intake side of the air pump has an O2 or N2 source

- ❏ The air pump has power running to it from wall mounted conduits
- ❏ The air pump is set to “on” (or “auto” if wired to sensor)
- ❏ If wired to a sensor, that sensor is in the same cabin as the air pump's outflow.

HEATING AND COOLING SYSTEMS

- ❏ Cabins are installed with heating unit
- ❏ Heating unit has power running to it from wall mounted conduits
- ❏ Cabins are installed with cooling unit
- ❏ Cooling unit has power running to it from wall mounted conduits
- ❏ Cooling and Heating units are set to “on” (or “auto” if wired to thermostat/s)

FINAL ENVIRONMENT CHECKS

- ❏ There are no visible signs of a leak, typically appearing as condensate/cloudy gases passing through gaps or holes
- ❏ Instruments read no change in pressure (kPa) in O_2, N_2 or CO_2 while pumps are inactive
- ❏ Canisters are stocked with O_2 or N_2
- ❏ Spare canisters with full charge are onboard