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Cooling Systems and Harsh Environments

Roger Rosborough
Market Development Consultant

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Agenda

- Cooling Systems
- Harsh Environments (Air temperature, air pressure, air quality)
  - Altitude
  - High Humidity and Coastal
  - Extreme Ambient Temperatures
  - Dust/ Particulate
- Harsh Environments (Earthquakes)
  - Seismic Certification
- Summary

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Cooling Systems

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Agenda

- Why do we need a Cooling System?
- Cooling Terminology
- Engine Coolant
- Enclosures
- Container Design
- Computational Fluid Dynamics (CFD)
- Additional Cooling system validation
- Summary

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- Cylinder temperature control is important to maintain a protective film of oil on the surfaces whilst the oil itself needs to be kept cool to work effectively

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- Thermal Efficiency
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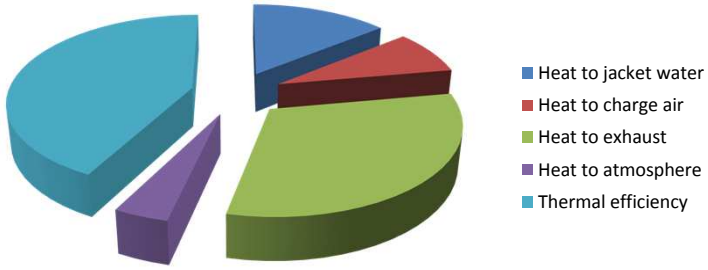

Engine and Cooling System Components for Heat transfer

Engine

- Engine Jacket water circuit
- Engine water pump
- Engine coolant
- Engine temperature regulator (thermostat)
- Engine pressure cap setting
- Engine oil & oil cooler
- Engine charge air circuit (where applicable)

Cooling System

- Cooling Fan
- Cooling system jacket water circuit
- Connecting pipework
- Cooling system charge air circuit (where applicable)

Cooling Terminology

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  - Site altitude above sea level (air density?)

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  - Site altitude above sea level (air density?)
  - Humidity at site (air density?)

Engine Coolant

- **Water**
  - Most efficient heat transfer medium
- **Glycol**
  - Provides protection against boiling, freezing and water pump cavitation
- **Additives**
  - Protect the metal surfaces of the cooling system
  - Protect against coolant foaming, corrosion and build up of scale
- **Additives**
  - Lower specific heat capacity than water alone
  - **CAT gensets typically use a 50% antifreeze mixture - Extended Life Coolant (ELC)**
  - Ambient capability decreases by approximately 1 DegC for each 10% of antifreeze added

Typical Spec Sheet Statement

"Cooling system designed for 50˚C operation"

Cooling system - Standard integral set-mounted radiator system, designed and tested for ambient temperatures up to 55 °C (131 °F), simplifies facility design requirements for rejected heat.

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- At what site conditions?
- How does the engine and alternator perform at this temperature and these site conditions?

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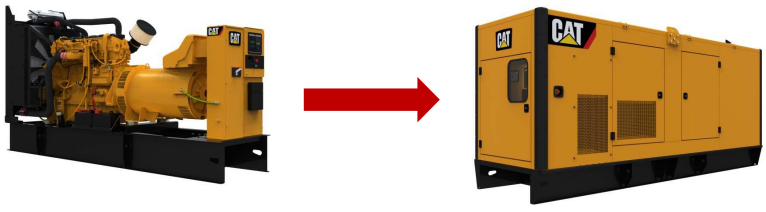
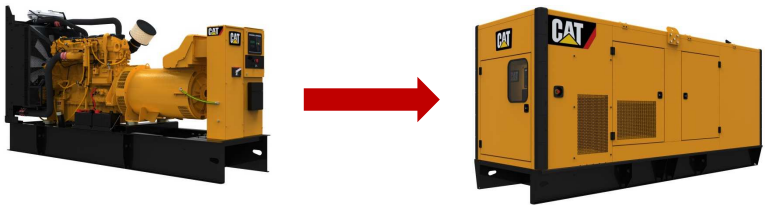
- At what site conditions?
- How does the engine and alternator perform at this temperature and these site conditions?
- What happens when an optional enclosure is selected?

Adding an Optional Enclosure



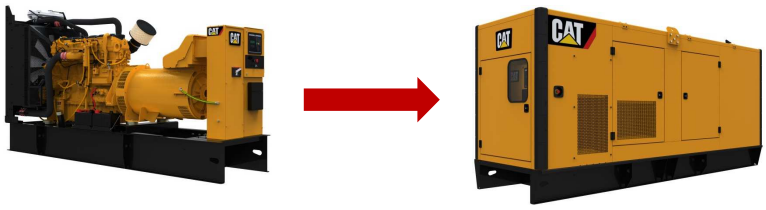
- Ambient capability ?

Adding an Optional Enclosure



- Ambient capability is reduced

Adding an Optional Enclosure



- Ambient capability is reduced
  - Restriction
  - Cooling air is heated by: alternator, exhaust manifold, turbo and exhaust pipework, heat radiated from cylinder block and head.
  - As the enclosure surface temperature increases this adds to the heating effect.

Enclosure Spec Sheet Data

C13 Example

50 Hz SA Enclosure (Low BSFC)			Ambient Capability*		Airflow Rate		Sound Pressure Levels dBA @ Full Load			Exhaust Back Pressure	
ekW	kVA	PP/SB	°C	°F	m³/s	cfm	1m	7m	15m	in H_2O	kPa
360	450	SB	49	120	5.6	11866	81.8	70.6	64.6	12.1	3.0
320	400	PP	49	120	5.6	11866	81.4	70.3	64.3	10.0	2.5

- Some manufacturers may not show the enclosure ambient capability.

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- Some manufacturers may not show the enclosure ambient capability.
  - It will be lower than the Open set and could be significantly lower, depending on the design!

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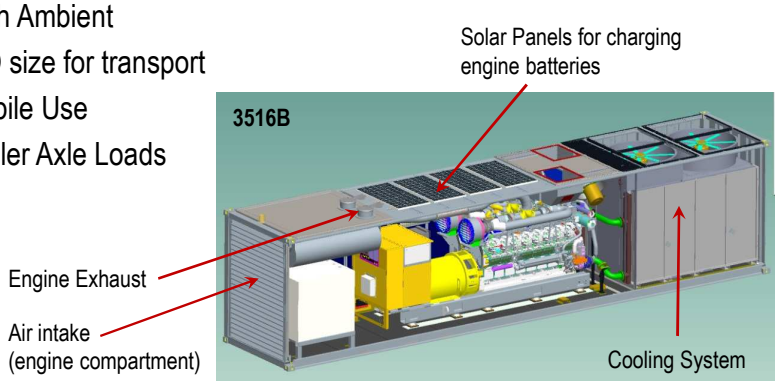
More Information Available from Cat Dealer

Percentage Load	Airflow Rate m3/min	Ambient Capability Sea Level (Deg C)	Ambient Capability 300 m (Deg C)	Ambient Capability 600 m (Deg C)	Ambient Capability 900 m (Deg C)
100	516	49	47	45	43
75	516	53	51	49	47

- Your Cat dealer has access to the “engine and cooling” ambient capability.
- SpecSizer

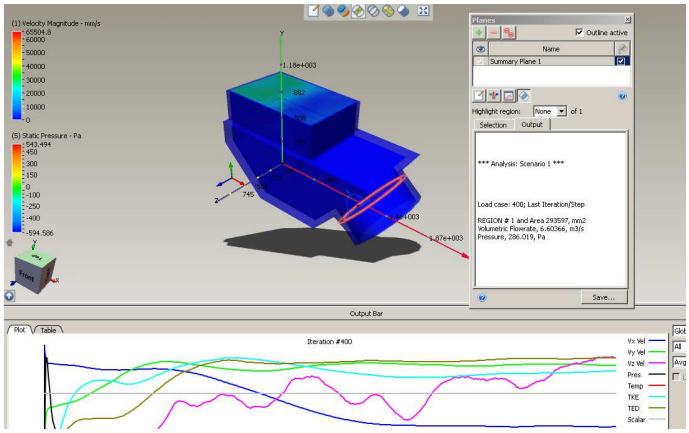
Container Design for Power Modules

- **EXAMPLE: MEW Kuwait Customer Requirements**
  - 1.8MVA
  - High Ambient
  - ISO size for transport
  - Mobile Use
  - Trailer Axle Loads

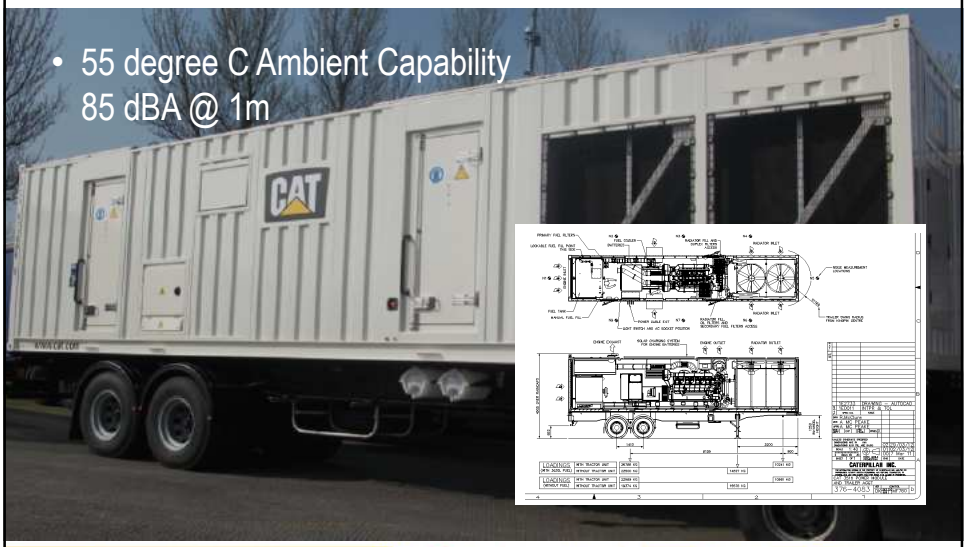


CFD model - engine compartment air flow

- Duct and Grill design optimised for pressure drop



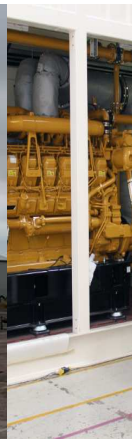
Performance



- 55 degree C Ambient Capability
  85 dBA @ 1m

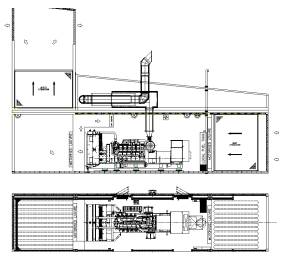
Low Ambient Containers

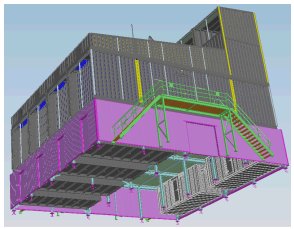
- **Customer Requirements**
  - 2 x 3512B
  - 3.3kV – 1.5MVA
  - **-40 to +20 Ambient**
  - 75dBA @1m
  - Exhaust Gas, JW & SCAC Heat Recovery

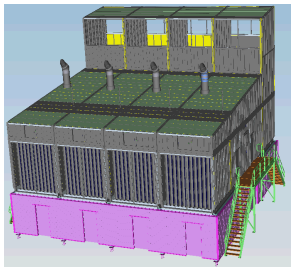


Datacentre Product

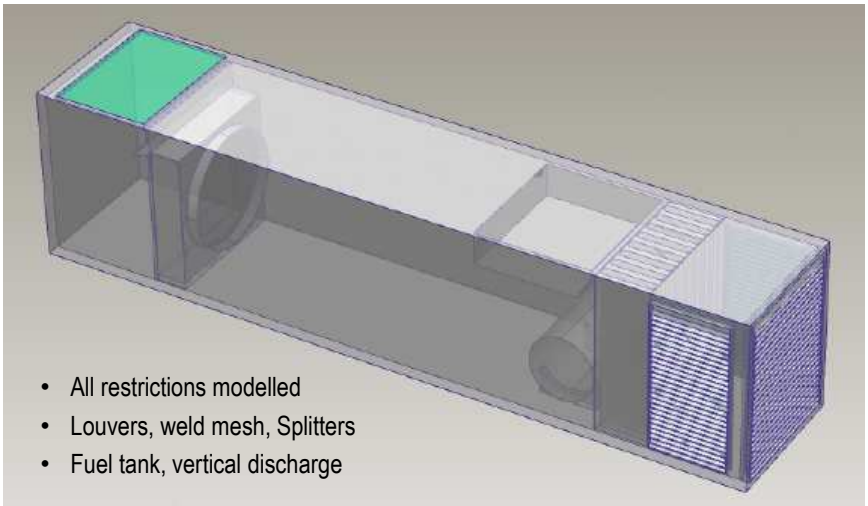
- **Customer Requirements**
  - 4 x 3512B @ 1875kVA each
  - 50dBA @ 50m ~= 66@1
  - **Ambient = -40 to +34 degC**
  - Air Recirculation system
  - Fire Suppression System – water mist







CFD modelling used for Generator Set Enclosure and Container designs

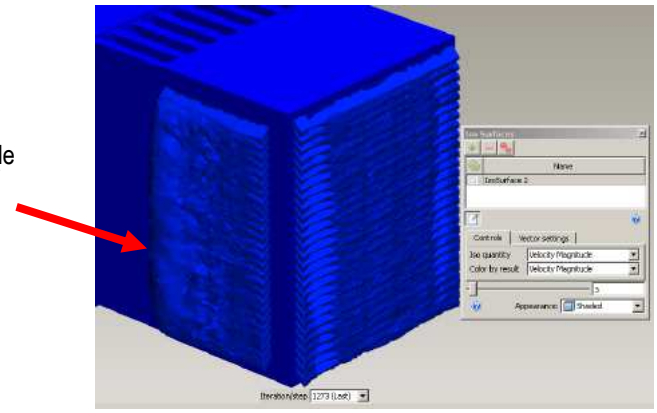


- All restrictions modelled
- Louvers, weld mesh, Splitters
- Fuel tank, vertical discharge

3512 – Air Intake Velocity Profile

Modelled with **Fan Curve with Tank with Splitters**
3m/s ISO Plot

- Higher velocity profile
- On closest edges of side louvers
- Similar to validation trends but higher values



3512 – Air Intake Velocity Profile (cont.)

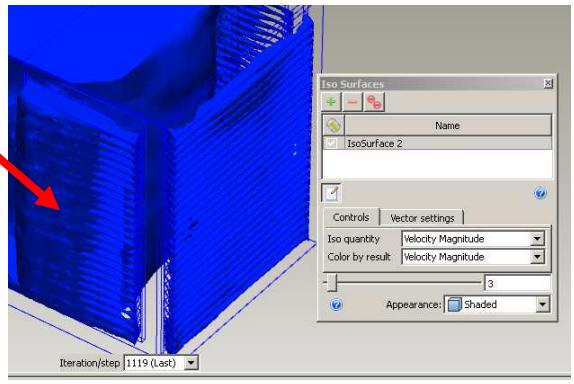
Modelled with **Fan Curve without Tank without Splitters**
3m/s ISO Plot

- Again shows higher velocity profile on closest edges of side louvers
- Similar to validation trends but higher values

Converges at 1119 iterations
1m elements

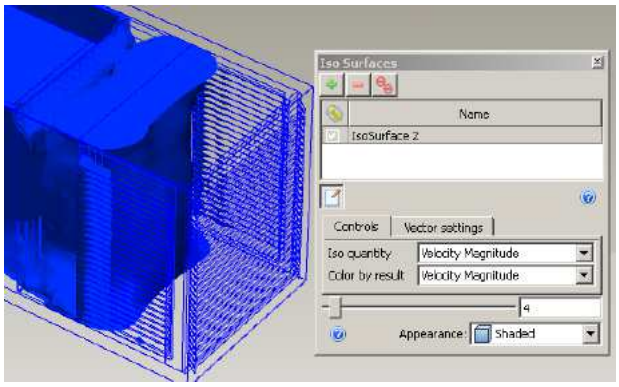
25.4m3/s (177PA)

+3.2% ON CFD



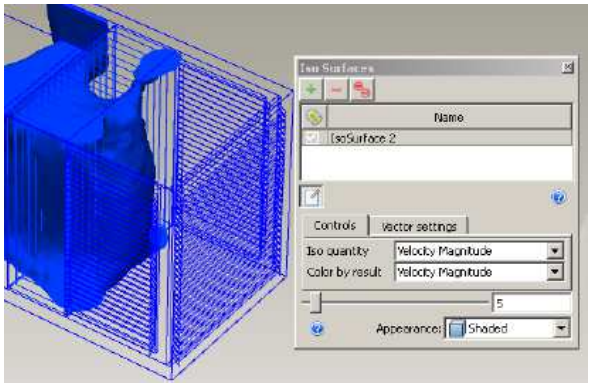
3512 – Air Intake Velocity Profile (cont.)

Modelled with **Fan Curve without Tank without Splitters**
4m/s ISO Plot



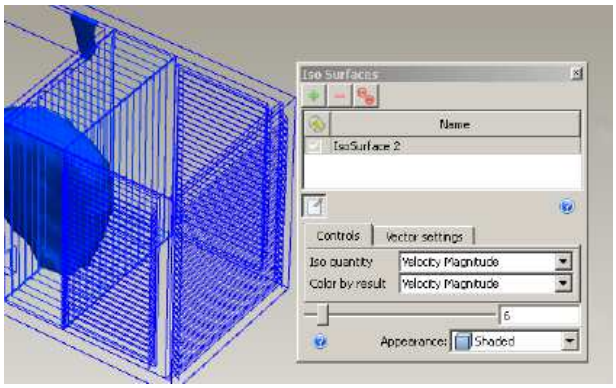
3512 – Air Intake Velocity Profile (cont.)

Modelled with **Fan Curve without Tank without Splitters**
5m/s ISO Plot



3512 – Air Intake Velocity Profile (cont.)

Modelled with **Fan Curve without Tank without Splitters**
6m/s ISO Plot



Additional Cooling System Validation

- In addition to air flow and thermal performance testing, Caterpillar also ensures the generator set is fitted with a practical, durable and efficient cooling system which will perform and protect the engine.
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  - Drawdown Capability

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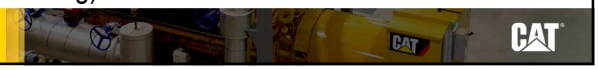
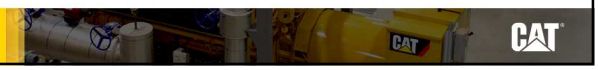
  - Hot shut down test
  - Reliability (Endurance testing)



Harsh Environment Considerations

- Altitude
- High Humidity and Coastal
- Extreme Temperatures
- Dust/Particulate



Altitude

- Derate
  - Above 500m and below 1500m (Engine vs. Radiator)
  - 1500m the engine derates much faster than the radiator
- Higher pressure cap
  - Boiling point of the coolant

High Humidity/Coastal

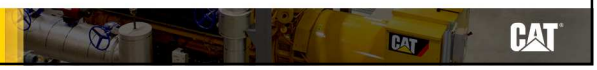
- Condensation and evaporation process
  - Salt corrosion
  - Standby vs. Prime/Continuous operation
- Radiator core coating
  - Heresite
- Frame
  - Galvanized
  - Plan to manage all steel components on the generator set

Extreme Temperatures

- > 50-55C
  - Decrease in efficiency due to decreasing heat gradient
  - Balance of fan speed vs. core size
- < 0C
  - Control of engine air inlet temperature
    - Space heaters
    - Recirculation: fan failures and/or louver damage
  - After cooler circuit (No thermostat)
    - Thermal shock on engine
      - Electrical controlled (custom not offered in Price list)
      - Mechanical (may have special offering, truck & petroleum app)

Dust/Particulate

- Radiator core clogging/plugging
  - Maintenance program
    - Cleaning: Air exit toward the inside
  - Single and Dual core
  - Fin spacing and type
- Fan degradation
  - Material hardness
  - More concerning with composite fans
  - Fan balance
  - Airflow velocity



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Harsh Environments (Earthquakes) Seismic Certification of Gensets

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Seismic Certification of Gensets

- Introduction
- Regulations
- Code and Certification
- Cat Certified Packages

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Earthquakes

- Van, Eastern Turkey (2011) registered 7.1 on the Richter Scale
  - 11,232 buildings damaged with over 6,000 uninhabitable
  - Estimated 60,000 people homeless
- Tohoko, Japan (2011) registered 9.0 on the Richter Scale
  - Largest earthquake on record in Japan
  - Created tidal wave over 40m tall
  - Shifted Earth's axis 10-24 cm
  - Over $235 billion in damage

Need a Reliable Source of Power

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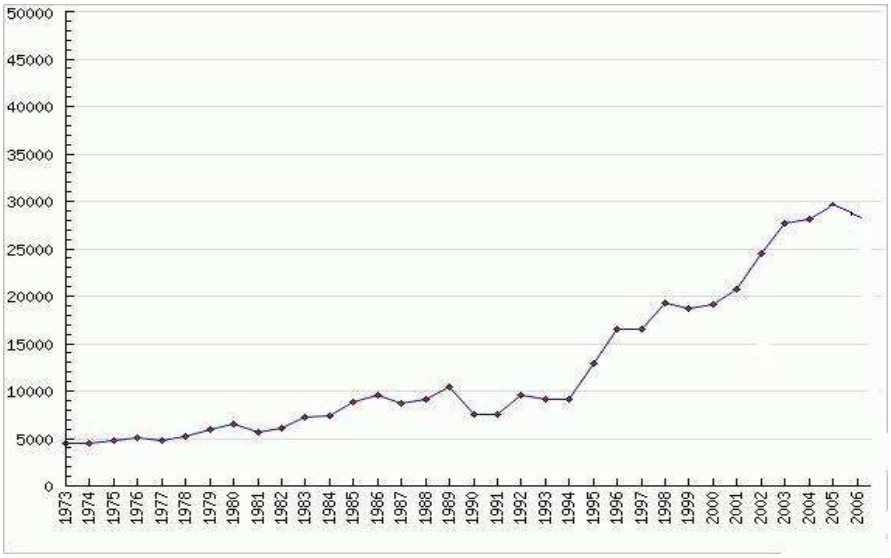
Frequency of Earthquakes



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Seismic Levels and Regulations

- No central governing agency worldwide
- Rooftop and ground certifications

International Building Code

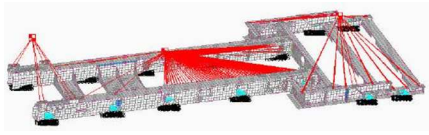
- Caterpillar certifies to IBC
  - Most stringent worldwide
- Governed by the International Code Council
- IBC references ASCE 7 for genset code requirements
  - Elaborate code of certification and calculations
  - Updated every 2 years
- Main concern is “Active and Energized” components

Caterpillar Certification Process

- Caterpillar Electric Power utilizes global experts
  - Understand current code and future changes
  - Daily interaction with certifying agency
  - Structural Engineers specialized in seismic activity
  - Perform all analysis and provide recommended design changes
  - Coordinate all testing, documentation, and obtaining approved certification

Obtaining Certification

- Multi step, lengthy, and costly process
- Consists of the following:
  - Analysis
  - Product design iteration
  - Shake table testing
  - Documentation



- 9-12 months for typical project duration
- Up to $500k (USD), excluding genset costs
  - Optimize global volume to minimize costs
- Documentation of product changes after certification

Shake Table

Certified Packages

- Currently Certified to Sds< 3.2g (ground)
  - Range from C27 to C175-20
  - Includes rooftop installations at Sds< 2.0g
  - Highest possible certification, dictated by latest ASCE 7
  - No other manufacturer is currently certified to this level
- New product exceptions
  - C175-20 package mounted rads – no plan
  - 3516E 50 Hz with OOB
  - 1750 ekW 60 Hz with OOB

Electronic Media Center: LEXE0920-00

Building Code: IBC 2012	*Seismic Certification Limits:*	S_{DS} = 2.00g S_{DS} = 3.20g	*z/h* = 1.0 *z/h* = 0.0	I_p = 1.5	

Model Line	Model	Dimension (in)			Max Wt. (lb)	Notes	UUT
		Depth	Width	Height			
C27 (≤800 kW)	Open – Min. package	163.1	72.0	87.0	14,050	*Open package inherently tested since tank is rigid.	1*
	Open – Max. package	172.0	84.0	86.0			
	Enclosed – No tank	300.0	100.0	111.9	22,827		
	Enclosed – 1000 gal.	300.0	100.0	127.0	36,332	*UUT: 60 Hz*	1
	Enclosed – 2000 gal.	300.0	100.0	136.0	43,660		
C32 (≤1000 kW)	Open – Min. package	166.7	79				
	Open – Max. package	177.0	84				2*
	Enclosed – No tank	300.0	10(				
	Enclosed – 1000 gal.	300.0	10(				
	Enclosed – 2000 gal.	300.0	10(				2
3512 (≤1250 kW)	Min. package	199.0	77				
	Max. package	214.2	81				
3512B (≤1280 kW)	Min. package	206.6	77				
	Max. package	218.2	81				

Model Line	Model
Global Design Box w/ EMCP 4 Controller (Caterpillar)	Base
	Side Ext. Box
	Rear Ext. Box
High Voltage Box w/ EMCP 4 Controller (Caterpillar)	HVB
Molded Case Circuit Breaker (Schneider)	NSJ Frame (600A max)
	L Frame (600A max)
	P Frame (1,200A max)
	R Frame (3,000A max)
	NT Frame (5,000A max)

Radiator (API Thermasys)	37SF
	44SF
	60SF
Generator (Leroy-Somer)	1200 Frame
	1400 Frame
	1600 Frame
	1800 Frame
	2700 Frame
	3000 Frame

Recap

- Seismic regulations
  - IBC certification is the most stringent
- Regulation Challenges & Process
  - Multistep, iterative
- Product Certification
  - Significantly increased product offering

Summary

- Cooling Systems
- Harsh Environments (Air temperature, air pressure, air quality)
- Harsh Environments (Earthquakes)
  - Seismic Certification
- Cat thoroughly design and test their generator sets to ensure a performance optimised durable product

Questions?

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