



Connecting For Success...

ELECTRIC POWER DAYS 2017

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CATERPILLAR®

Cooling Systems and Harsh Environments

Generator Sets

Roger Rosborough

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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

Cooling Systems Agenda

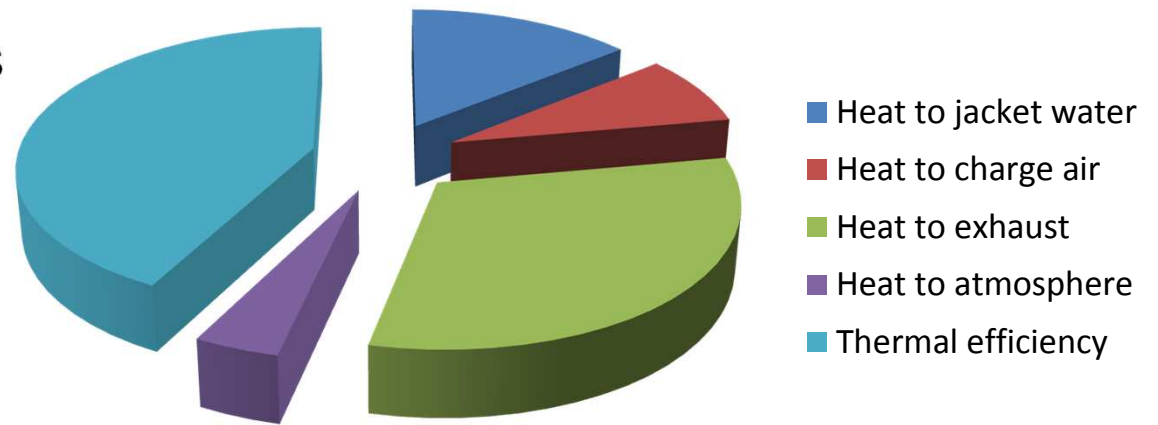
- Why do we need a Cooling System?
- Cooling Terminology
- Engine Coolant
- Enclosures
- Container Design
- Computational Fluid Dynamics (CFD)
- Additional Cooling system validation
- Summary

Why do we need a Cooling System?

- Internal combustion engines create heat as a result of combustion and friction between moving parts
- Major engine components such as pistons, cylinder heads and valves need to be kept cool to prevent damage
- 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

Why do we need a Cooling System?

- Thermal Efficiency
 - X% of the energy in fuel ends up as usable power
- What happens to the rest of the energy?



Cooling Terminology

Ambient capability (ambient clearance)

- Maximum ambient temperature in which the cooling system can operate effectively without causing the generator set to shutdown due to high engine temperature.
- Site conditions affect the ambient capability and include.....
 - External restriction to cooling airflow (higher restriction, lower air flow)
 - 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°C for each 10% of antifreeze added



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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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Typical Spec Sheet Statement

“Cooling system designed for 50°C operation”

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At what site conditions?

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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?

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Adding an Optional Enclosure



- Ambient capability is reduced or increased?

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Adding an Optional Enclosure



- Ambient capability reduced because of
 - 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.

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Enclosure Spec Sheet Data



C15 Example

Model	kVA	ekW	SB/PP	LWA	Sound Pressure Levels dBA				Air Flow Rate		Ambient Capability at 100% Load*	
					1m (3.3 ft)		7m (23 ft)					
					75% Load	100% Load	75% Load	100% Load	m³/s	cfm	°C	°F
50 Hz												
DE500E0	455	364	PP	98	79	79	69	70	5.7	12078	44	111
	500	400	SB	98	79	80	69	70	5.7	12078	45	113

- Some manufacturers may not show the enclosure ambient capability.

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Enclosure Spec Sheet Data



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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

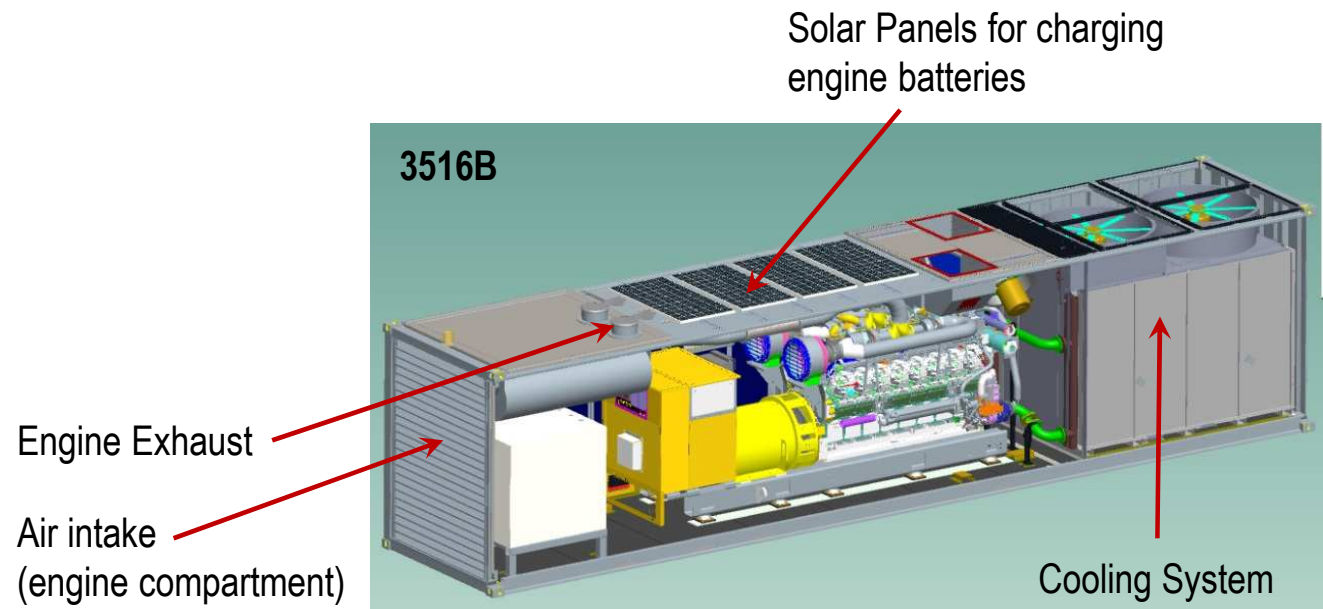
- Your Cat dealer has access to the “engine and cooling” ambient capability.
- SpecSizer

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Container Design for Power Modules

- **EXAMPLE: MEW Kuwait Customer Requirements**

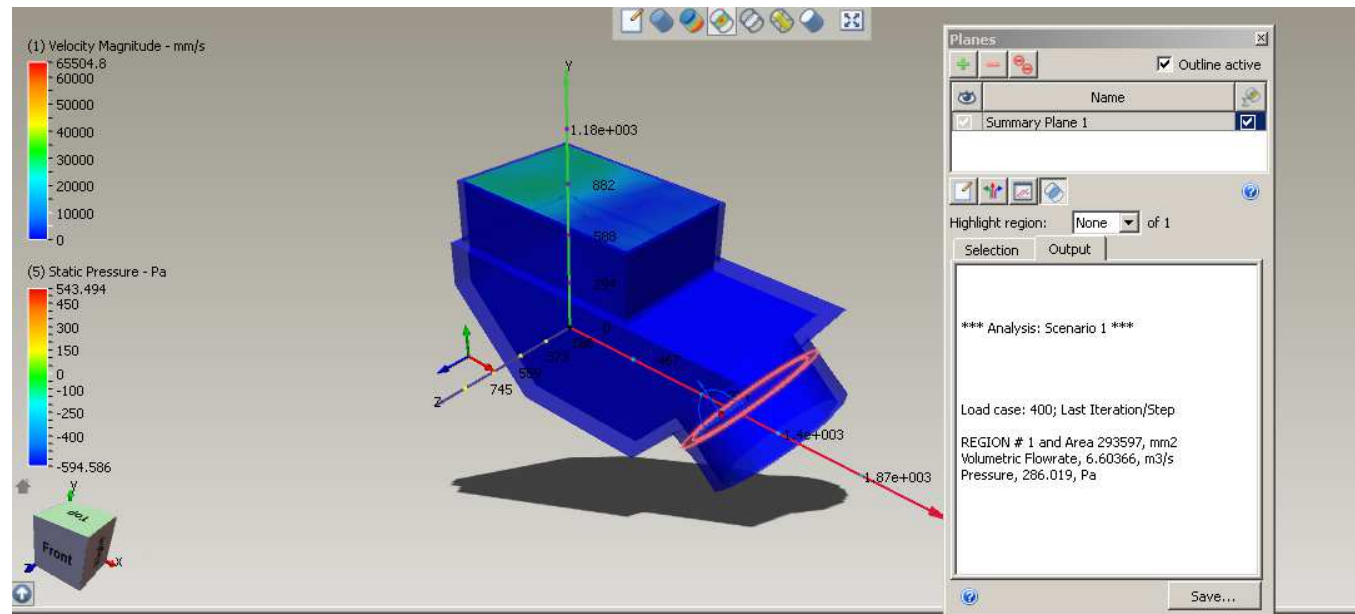
- 1.8MVA
- High Ambient
- ISO size for transport
- Mobile Use
- Trailer Axle Loads



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CFD model - engine compartment air flow

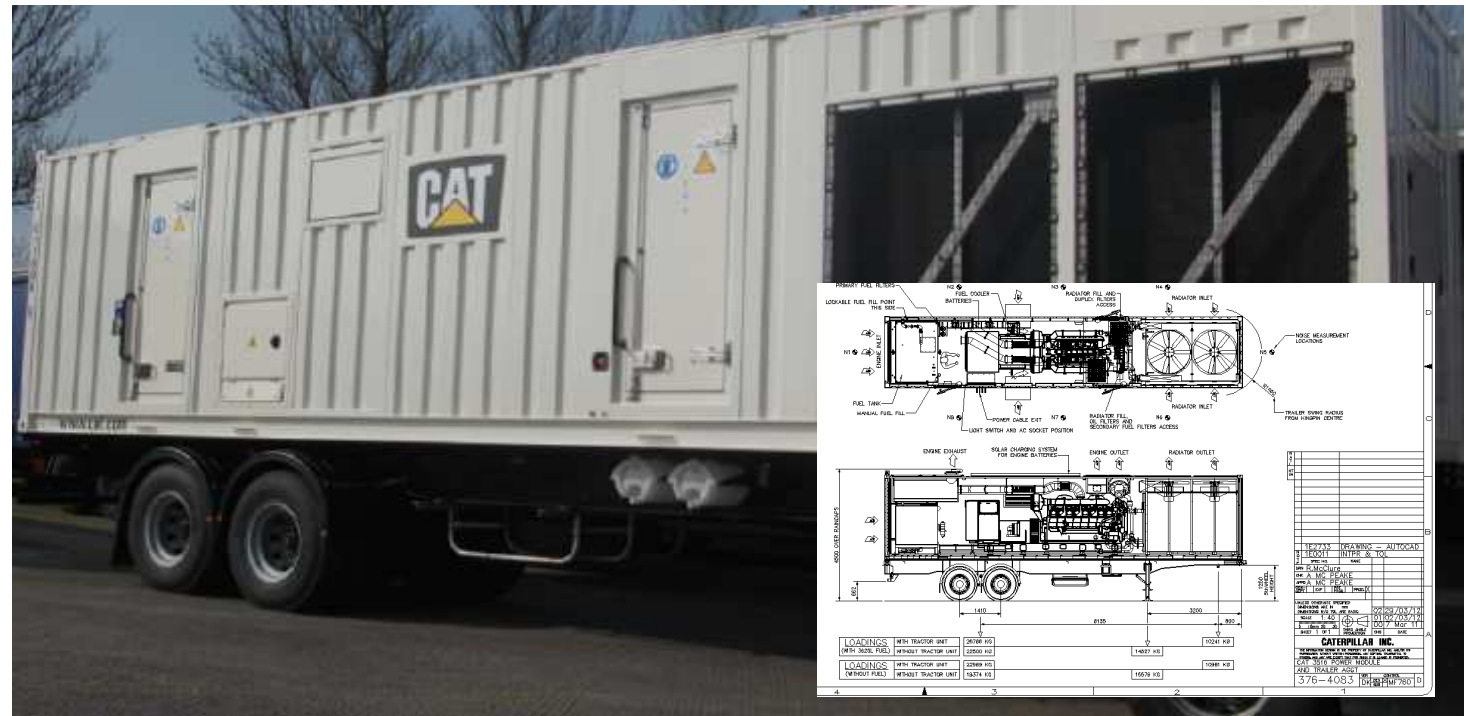
- Duct and Grill design optimised for pressure drop



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Performance

- 55 degree C Ambient Capability
- 85 dBA @ 1m



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Low Ambient Containers

- **Customer Requirements**

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

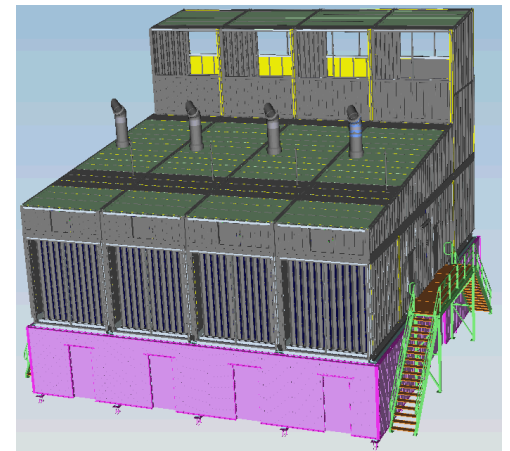
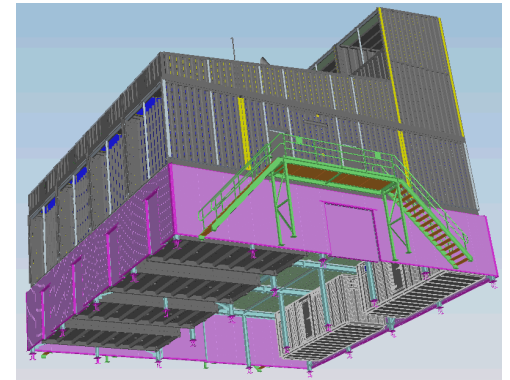
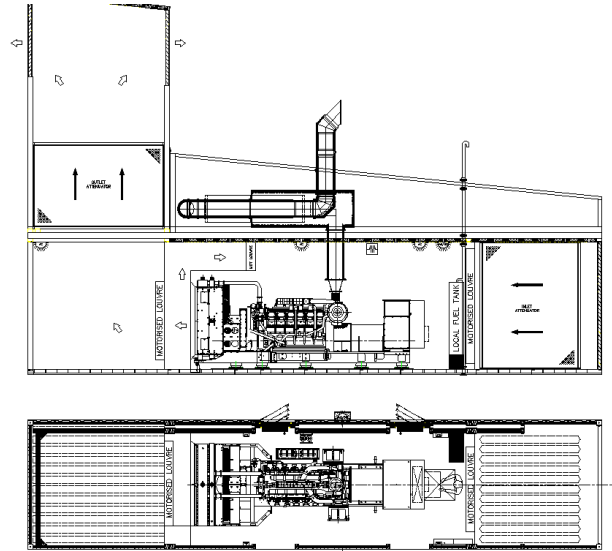


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Datacentre Product

- **Customer Requirements**

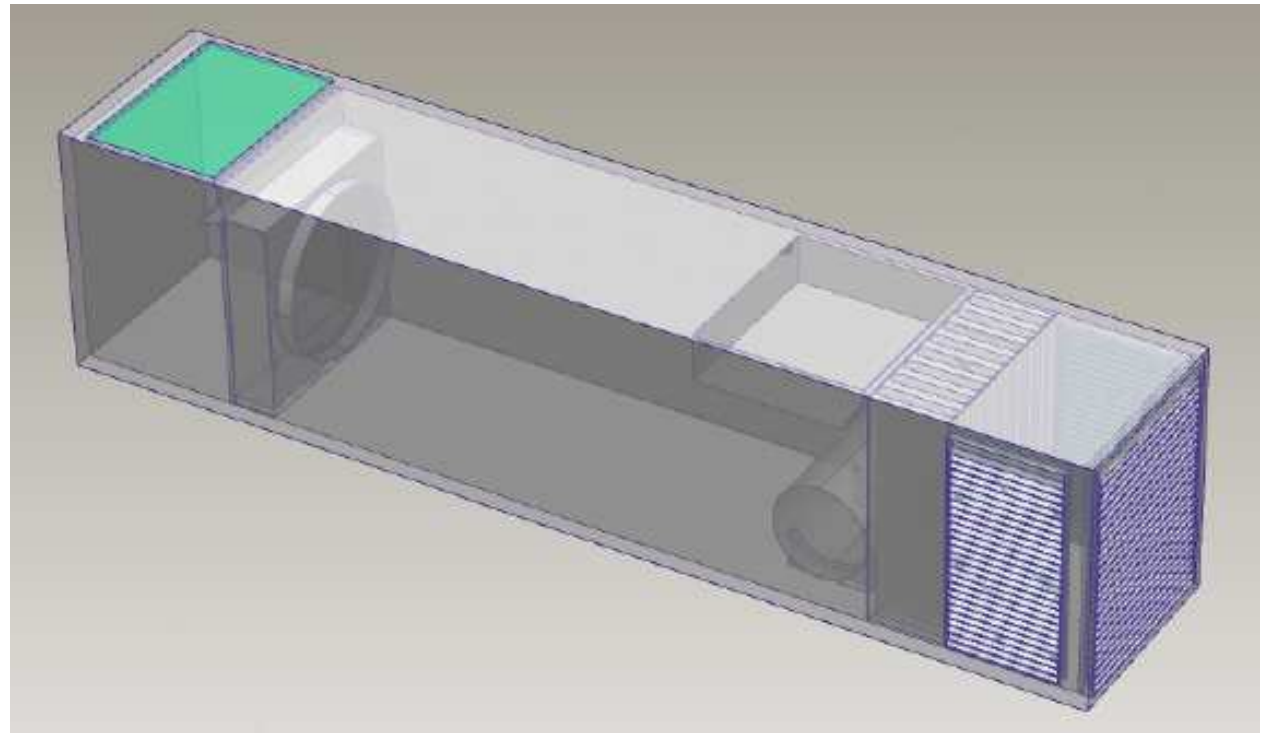
- 4 x 3512B @ 1875kVA each
- 50dBA @ 50m ~ = 66@1
- **Ambient = -40 to +34 degC**
- Air Recirculation system
- Fire Suppression System – water mist



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CFD modelling used for Generator Set Enclosure and Container Designs

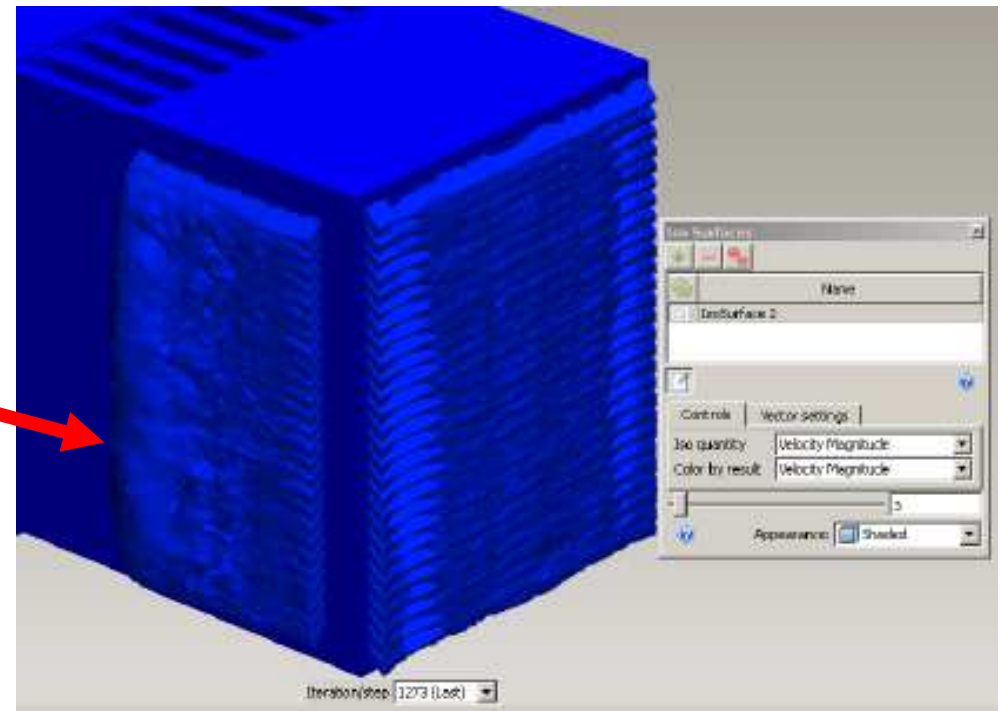
- All restrictions modelled
- Louvers, weld mesh, Splitters
- Fuel tank, vertical discharge



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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



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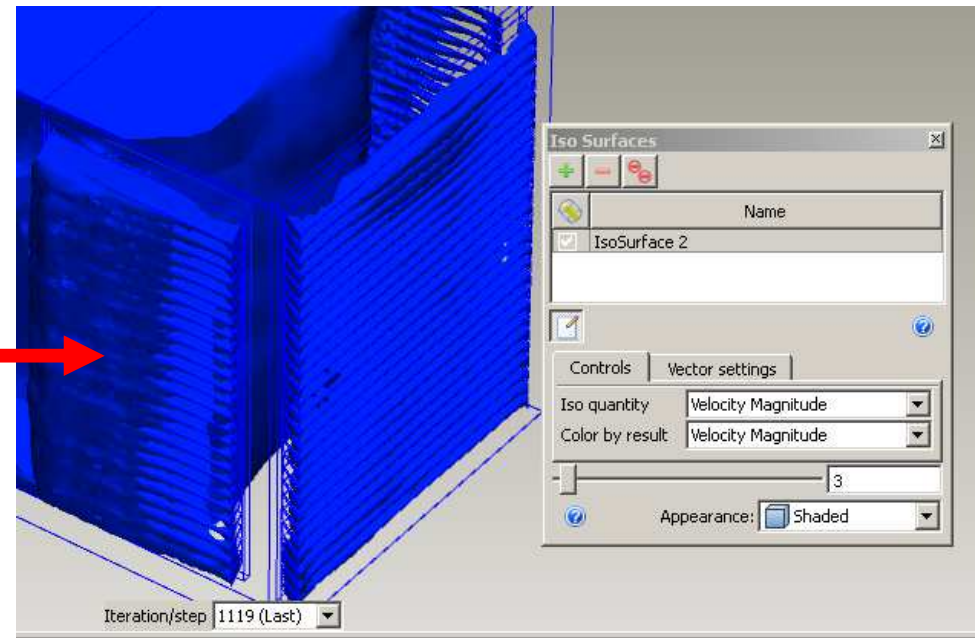
3512 – Air Intake Velocity Profile (cont.)

- 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

Converges at 1119 iterations 1m elements

25.4m³/s (177Pa)

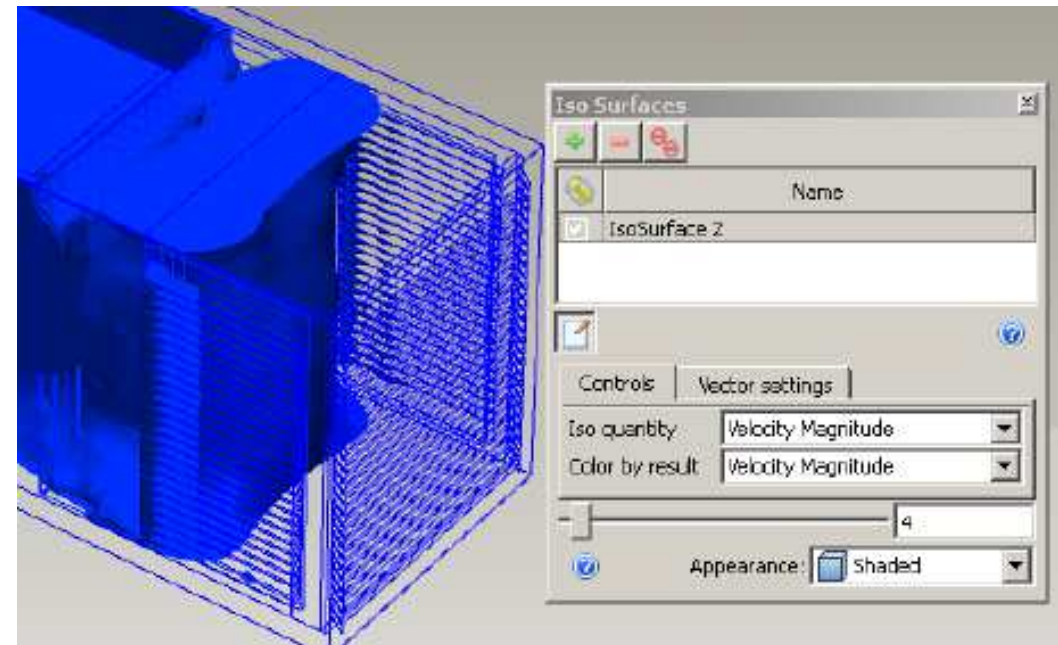
+3.2% ON CFD



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3512 – Air Intake Velocity Profile (cont.)

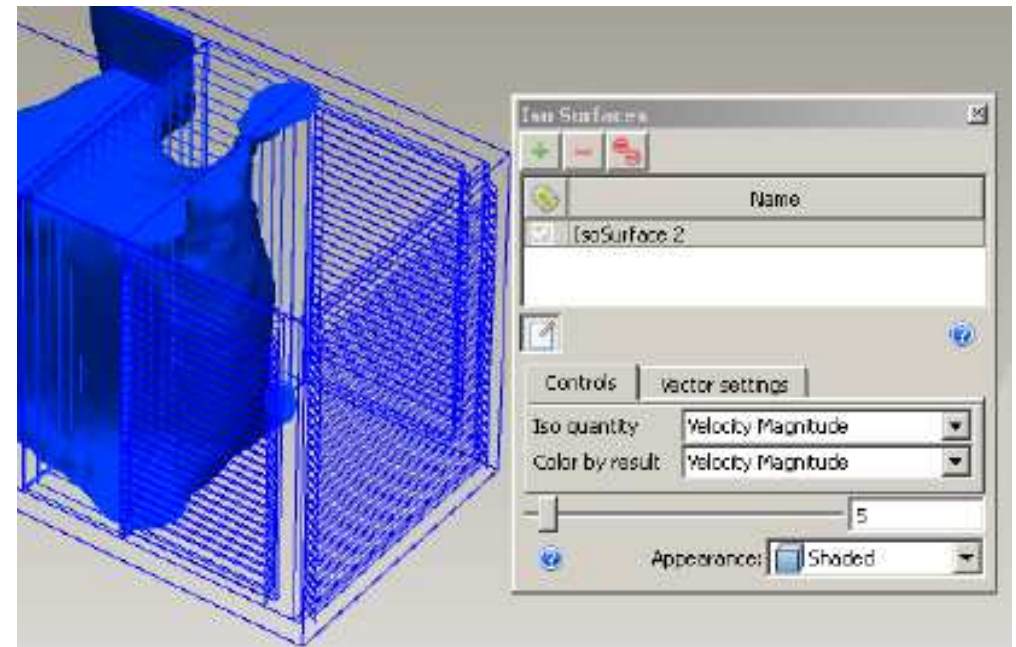
- Modelled with **Fan Curve without Tank without Splitters**
- 4m/s ISO Plot



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3512 – Air Intake Velocity Profile (cont.)

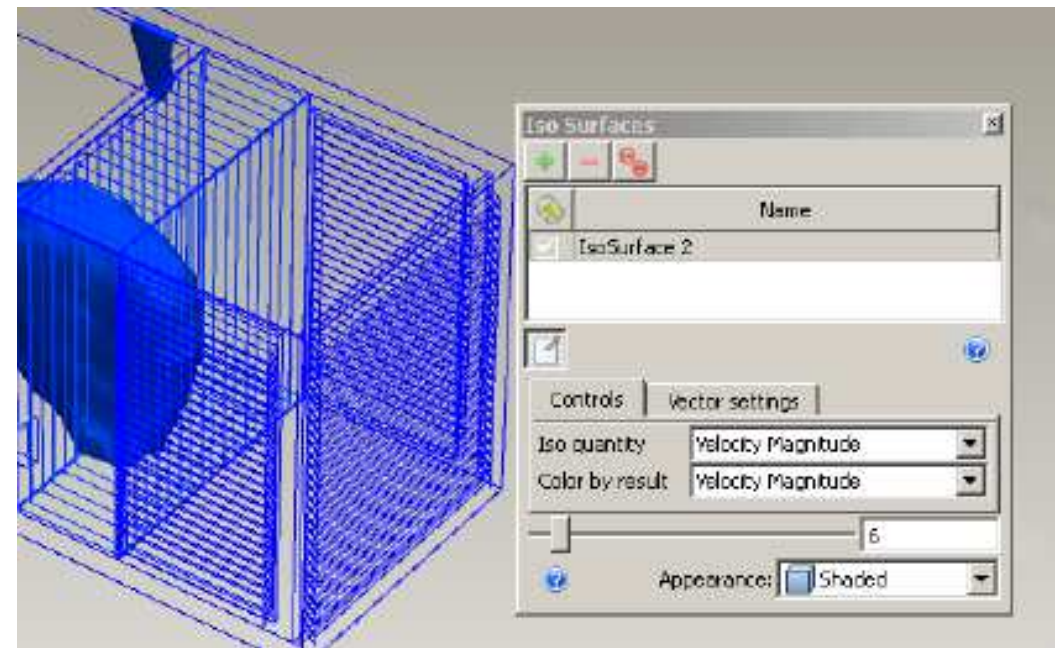
- Modelled with **Fan Curve without Tank without Splitters**
- 5m/s ISO Plot



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3512 – Air Intake Velocity Profile (cont.)

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



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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.
- The following tests are also carried out to ensure high standards are maintained:

Additional Cooling System Validation

- Filling Test (adequate fill rate without trapping air in system)
- Pump Cavitation
- Drawdown Capability
- Air Venting Ability
- Hot shut down test
- Reliability (Endurance testing)

Harsh Environment Considerations

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

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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 (can order space heater option)
 - Alternator protection (can order CIP coastal insulation protection or Form wound)
- 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
 - Electrically 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

Harsh Environments (Earthquakes) – Seismic Certification of Generator Sets

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

Earthquakes

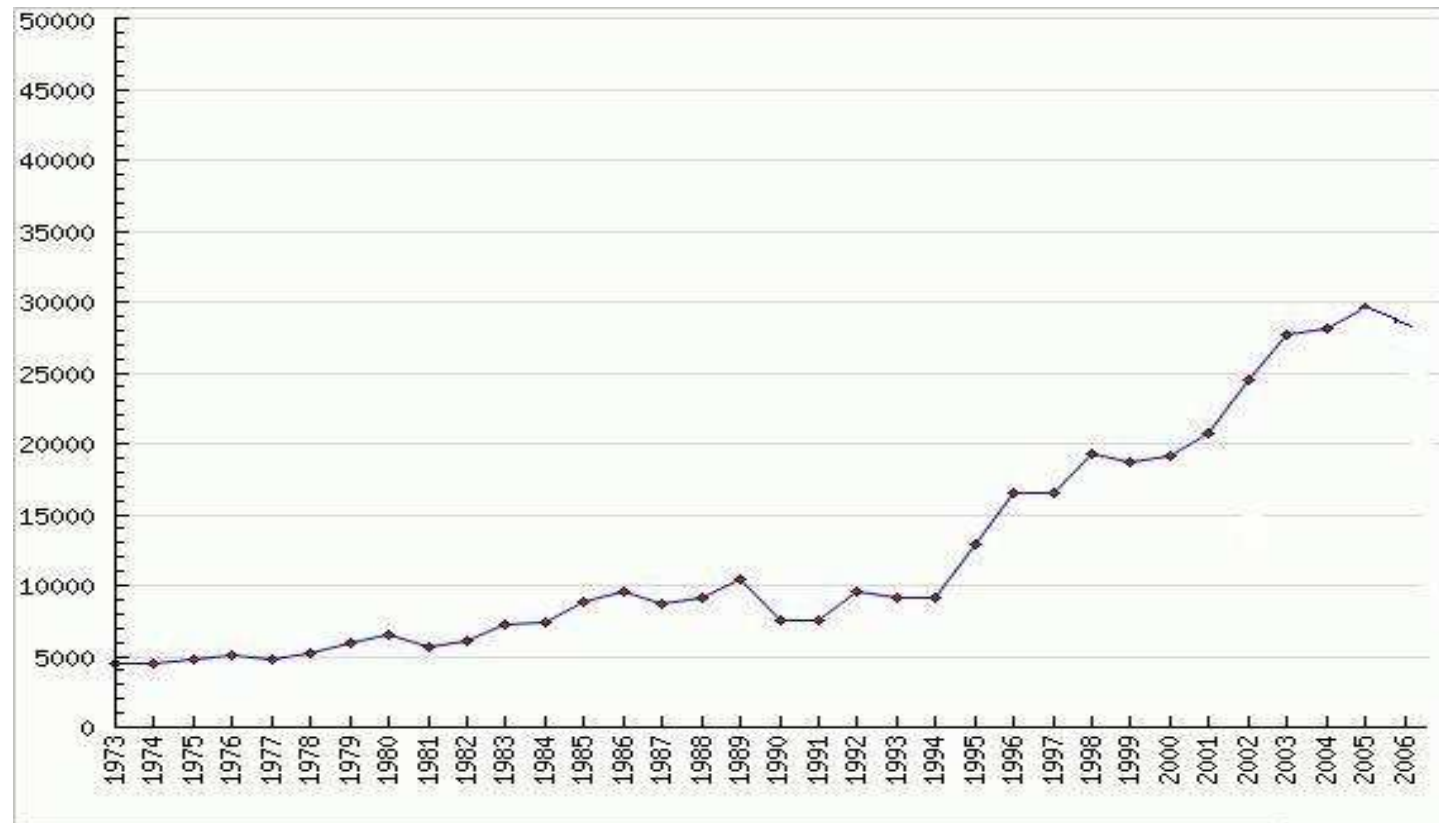
- Van, Eastern Turkey (2011) registered 7.1 on the Richter Scale
 - 11,232 buildings damaged with over 6,000 uninhabitable
 - Estimated 60,000 people homeless
- Tohoko, Japan (2011) registered 9.0 on the Richter Scale
 - Largest earthquake on record in Japan
 - Created tidal wave over 40m tall
 - Shifted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

Need a
Reliable
Source of
Power



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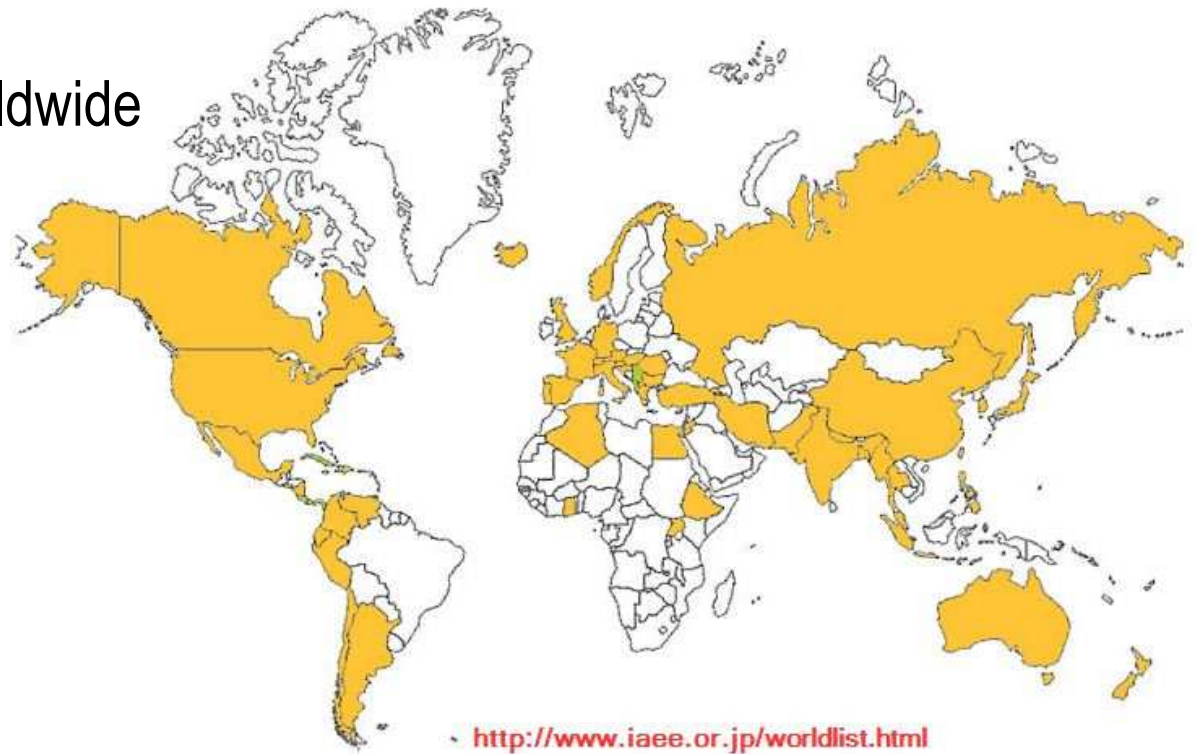
Frequency of Earthquakes



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Seismic Levels and Regulations

No central governing agency worldwide



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International Building Code

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



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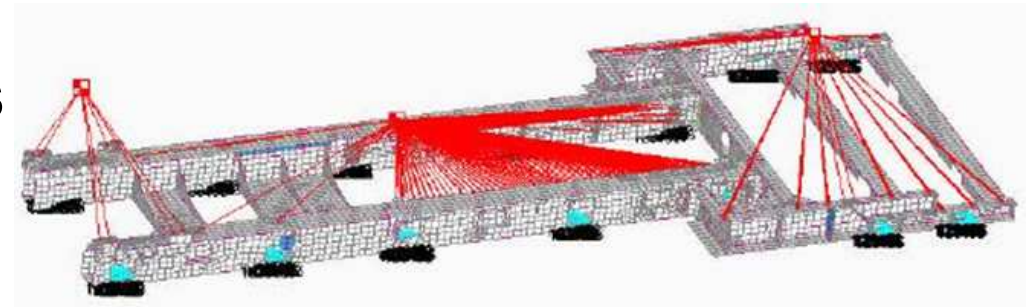
Caterpillar Certification Process

- 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

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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



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Shake Table



[Video Link](#)

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Certified Packages

- Currently Certified to $S_d < 3.2g$ (ground)
 - Range from C27 to C175-20
 - Includes rooftop installations at $S_d < 2.0g$
 - Highest possible certification, dictated by latest ASCE 7
 - **No other manufacturer is currently certified to this level**
- Product exceptions
 - C175-20 package WITH mounted rads – no plan
 - Upgradeable package designs

Vibration Isolators

- IBC Certification requires selection of correct Vibration Isolators from Price List

MOUNTING SYSTEM

No Isolators

6	NOISO01	NO ISOLATORS 0
		TECHNICAL: Removes shipped loose rubber isolators to be placed under the package and radiator rails. However flexible mounts must be placed between the structural base of the auxiliary unit (Genset) and the foundation structure. Refer to A&I guide.
		CANNOT BE USED WITH: Enclosures (ENCSA72, ENCSA73, ENCSA74)

Puck Style Low Efficiency Isolators

6	VIBIS97	STANDARD PACKAGE ISOLATORS 0
		TECHNICAL: Provides shipped loose round rubber elastomeric isolators to be placed under the package rails
		CANNOT BE USED WITH: Enclosures (ENCSA72, ENCSA73, ENCSA74) or (IBCOSH1 or IBCCERT

Spring Type Vibration Isolators

6	VIBIS51	SPRING TYPE VIBRATION ISOLATOR 0
		TECHNICAL: Shipped loose. Spring-type vibration isolators with 95% efficiency.
		CANNOT BE USED WITH: Enclosure (ENCSA72, ENCSA73, ENCSA74) IBCOSH1 or IBCCERT

IBC Vibration Isolators

6	VIBIS50	SPRING TYPE VIBRATION ISOLATOR 0
		TECHNICAL: Shipped loose. Spring-type vibration isolators for seismic applications.

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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	79.1	85.0	18,200	* Radiator (API Thermasys)	37SF			
	Open – Max. package	177.0	84.0	85.0			44SF			
	Enclosed – No tank	300.0	100.0	111.9	25,300	Generator (Leroy-Somer)	60SF			
	Enclosed – 1000 gal.	300.0	100.0	127.0	38,806		1200 Frame			
	Enclosed – 2000 gal.	300.0	100.0	136.0	46,130		1400 Frame			
3512 (≤1250 kW)	Min. package	199.0	77.8	93.2	34,620		1600 Frame			
	Max. package	214.2	81.6	93.2			1800 Frame			
3512B (≤1280 kW)	Min. package	206.6	77.8	93.2	39,117		2700 Frame			
	Max. package	218.2	81.6	93.2			3000 Frame			

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)

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Recap

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

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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

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