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Overview of Customer Delivery Center

• New construction (2015)
• 3-story multi-use office building
• Airplane terminal, warehouse, event and business center
• Private, secured 130-acre occupant-owner industrial facility adjacent to county airport
Project Description
Seattle Customer Delivery Center

- Construction Type: 1A, 3-Story and Penthouse
- Fire Protection: Automatic Sprinkler System
- Building Height: 63’-0”
- Separation Distance: ≥ 30’; addition to existing 1A
- Occupancy Groups:
  - B (Business, Main Occupancy)
  - A-3 (Assembly, Conference)
  - S-1 (Storage, Moderate Hazard)
- Building Area by floor:
  - First: 31,462sf
  - Second: 34,575sf
  - Third: 25,884sf
  - Penthouse: 3,943sf
  - Total: 95,864sf
Code Summary
Applicable Codes & Standards

- International Fire Code (2012)
  - as amended in chapter 51-54A Washington Administrative Code (2013),
  - with King County Fire Code modifications/substitutions
- Fire Suppression Systems
  - FM Global Loss Prevention Standards DS 2-0, 2-8, 3-26, 4-4N and 3-10
- Fire Detection & Alarm
Occupancy & Separation

First Floor

- Assembly
- Accessory to Group B
- Storage Accessory Assembly
- Group A-3
- Business Group B
- Storage Group S-1
- Non separated Accessory To Grp B Per 508.2.1, 1004.3
- Restrooms
- Utility (Elec/Mech)
- Elevators
- Exit
- Exit stairs
- Exit access
- 1-Hr Fire Barrier
- 2-Hr Fire Barrier
- Occupancy Separation

Existing Office Building (not shown)
Occupancy & Separation
Second Floor

Existing Office Building (not shown)

Business Group B

Assembly
Group A-3

Per 508.2.1, 1004.3

Occupancy Separation

Restrooms

Utility (Elec/Mech)

Elevators

Exit

Exit stairs

Exit access

1-Hr Fire Barrier

2-Hr Fire Barrier

Assembly
Separated Grp A-3

Business Grp B

Storage Grp S-1

Non separated
Accessory
To Grp B

Per 508.2.1, 1004.3

Assembly
Accessory to
Group B

Business
Group B

Non separated
Accessory
To Grp B

Per 508.2.1, 1004.3
Occupancy & Separation
Third Floor

Assembly Accessory to Group B

Business Grp B

Storage Grp S-1

Non separated Accessory To Grp B Per 508.2.1, 1004.3

Restrooms

Utility (Elec/Mech)

Elevators

Exit

Exit stairs

Exit access

1-Hr Fire Barrier

2-Hr Fire Barrier

Occupancy Separation
Occupant Load
First Floor Lobby Area Seating Alternatives
2,323sf, 155 occupants (15sf/person (net) supports unconcentrated tables & chairs)

• Club-style seating for 23
  • 7 chairs, 4 two-person sofas,
  • 4 two-person tables

• Preferred daily seating for 54
  • 11 four-person tables,
  • 5 two-person tables

LSC Table 7.3.1.2
Occupant Load
Second Floor Multi-Use Area with Theater Style Layout
4,184sf, 280 occupants (15sf/person (net) supports concentrated layout)

212 chairs shown
6sf per chair

Posted Occupancy Limit

Seating for Event
Egress Requirements

• Fire Separation of Occupancies and Paths of Egress
  • Fire separation per IBC 508.4.
  • Travel distance and common paths per IBC 1015.2.1, 1016.2 and 1014.3.

• Exit Discharge
  • Direct and unobstructed access to a public way, per IBC 1027.

Main Entrance on West
Egress
Requirements (cont’d)

• Fire Resistance Rating and Interior Finishes
  • Interior finishes provided in exits, corridors and spaces exceed the minimum fire performance and smoke development ratings required by the IBC 803 and 804.

• Number, arrangement and capacity of exits
  • Corridor and exit width and arrangement based on occupant load meet IBC 1005, 1018 and 1021.
Egress
Means of Egress, Exit Discharge
## Egress

### Number, Arrangement and Capacity of Exits

<table>
<thead>
<tr>
<th>Floor/Space</th>
<th>Occupant Load</th>
<th>Exits Required</th>
<th>Exit Width Required per exit (in)</th>
<th>Exit Width Required Floor</th>
<th>Exit Width Provided, each</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seating</td>
<td>155</td>
<td>2</td>
<td>15.5</td>
<td></td>
<td>64 ea.</td>
</tr>
<tr>
<td>Luggage room</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>(.2&quot;)[3]=.6</td>
<td>36</td>
</tr>
<tr>
<td>Assembly Areas total</td>
<td>158</td>
<td>2</td>
<td>15.5</td>
<td></td>
<td>64 ea.</td>
</tr>
<tr>
<td>Break Room</td>
<td>165</td>
<td>2</td>
<td>16.5</td>
<td></td>
<td>36 ea.</td>
</tr>
<tr>
<td>Locker room</td>
<td>26</td>
<td>1</td>
<td>1</td>
<td>(.2&quot;)[26]=5.2</td>
<td>36</td>
</tr>
<tr>
<td>Men</td>
<td>7</td>
<td>1</td>
<td>1</td>
<td>(.2&quot;)[7]=1.4</td>
<td>36</td>
</tr>
<tr>
<td>Women</td>
<td>7</td>
<td>1</td>
<td>1</td>
<td>(.2&quot;)[7]=1.4</td>
<td>36</td>
</tr>
<tr>
<td>Business Area total</td>
<td>205</td>
<td>2</td>
<td>20.5</td>
<td></td>
<td>65 ea.</td>
</tr>
<tr>
<td>Parts Control Area 72</td>
<td>37</td>
<td>1</td>
<td>7.4</td>
<td></td>
<td>36</td>
</tr>
<tr>
<td>Warehouse</td>
<td>30</td>
<td>2 per IBC 1015.1</td>
<td>3</td>
<td>(.2&quot;)[30]=6.0</td>
<td>36</td>
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<tr>
<td>First Floor</td>
<td>430</td>
<td>2 per IBC Table 1021.2 (2)</td>
<td>5</td>
<td>(.2&quot;)[430]=86</td>
<td>324&quot; (4@65, 1@64)</td>
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<tr>
<td>Second Floor (rooms not shown)</td>
<td>635</td>
<td>4 separated occupancy</td>
<td>4</td>
<td>(.3&quot;)[635]=190.5</td>
<td>Business and Assembly</td>
</tr>
<tr>
<td>Third Floor (rooms not shown)</td>
<td>389</td>
<td>2 per IBC 1021.2</td>
<td>2</td>
<td>(.2&quot;)[389]=38.9</td>
<td>36“ 40” doors 60” stairs = 120</td>
</tr>
</tbody>
</table>

- Doors to stairways were increased in width prior to construction as a result of analysis.
Structural

- Type I-A Construction
- Multiple uses and auxiliary occupancies in the building.
- Existing Building is Type I-A, sharing common wall.
- Owner specifies that new construction shall accommodate future change in use.
- Exceeds usage requirements
  - First: 31,462sf  B, A-3, S-1
  - Second: 34,575sf  B, A-3
  - Third: 25,884sf  B

A = building area per story, S = stories above grade plane, UL = Unlimited, NP = Not permitted.
Structural

- Primary structure 3-hour rated system
- Typical 2-hour rated lightweight concrete decks
- Roofs 1 ½-hour fire rated assemblies
  - (FM Class 1)
  - concrete on steel deck layered with insulation and membrane cover

1st Floor Construction, Lobby & Assembly Area
Structural

- Common wall between existing Office building and new Assembly area is a 1-hr fire barrier
- Exit from new second floor assembly area
  - goes through existing building to north
  - then down a 2-hr barrier stairway
  - and a horizontal exit corridor with 2-hr barrier construction to discharge
- 1-hr barrier between new Assembly and Office areas on the second floor
- 60 minute rated cross-corridor accordion folding fire doors for assembly area on second floor (45 minute required).

*Example Folding Fire Door 2nd Floor*
Sprinkler System Summary

• Automatic Sprinkler System
  • Wet pipe sprinkler for heated interior areas.
  • Wet standpipe system for stairwells.
  • Combination wet standpipe/sprinkler system.
  • Dry pipe for unheated overhangs, canopies, and air handlers.
  • Wet pipe sprinkler for elevator shafts at the first level and elevator equipment rooms at the top level (third or penthouse).
Sprinkler Requirements

• Hazard Occupancy:
  • Light Hazard
    • Business
    • Main Occupancy
  • Ordinary Hazard Group 2
    • Mechanical & electrical rooms
    • Baggage areas
    • Kitchens
    • Storage less than 8 ft
  • Extra Hazard Group 1
    • Loading Dock

• Storage
  • Classified Commodity
Sprinkler Requirements

• Exterior
  • Second floor balconies wrap around the assembly area
  • Third floor balconies allow customers viewing access to their new airplane
  • Unprotected spaces and other covered load/unload areas require a dry pipe system.
  • Outside covered walkways on the ground floor are sprinklered by owner policy, susceptible to transient combustibles.

Airplane Stall Area Construction, North-East
Sprinkler Requirements

- Interior
  - Auxiliary spaces are ordinary hazard areas.
    - passenger screening areas
    - airplane access gates
    - luggage screening
    - and storage room
Sprinkler Requirements

• Interior (continued)
  • Warehouse area used to store customer items vary widely in combustibility, configuration and class.
  • Cartoned Unexpanded Plastic commodities will be stored on open racks.
Sprinkler

Two Sources

- Primary Source Industrial Loop:
  - 12” fire line around local buildings
  - 6” pipe from loop into riser room
- Test data at point of connection
  - Static pressure: 133 psi
  - Residual pressure: 105 psi
  - Flow: 2035 gpm

- Secondary Source City Water available at the pump house

### Sprinkler Water Supplies

<table>
<thead>
<tr>
<th>Source</th>
<th>Type</th>
<th>Rating (gpm @ psi)</th>
<th>Churn (tested)</th>
<th>~150% @ 65% (tested)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pump 1</td>
<td>Diesel</td>
<td>2000 @ 100</td>
<td>0 @ 114</td>
<td>2953 @ 63</td>
</tr>
<tr>
<td>Pump 2</td>
<td>Diesel</td>
<td>1000 @ 100</td>
<td>0 @ 105</td>
<td>1444 @ 88</td>
</tr>
<tr>
<td>Pump 3</td>
<td>Electric</td>
<td>2000 @ 100</td>
<td>0 @ 115</td>
<td>3062 @ 72</td>
</tr>
<tr>
<td>Pump 4</td>
<td>Electric</td>
<td>2000 @ 100</td>
<td>0 @ 114</td>
<td>3173 @ 72</td>
</tr>
<tr>
<td>City</td>
<td></td>
<td>2295 @ 124</td>
<td>0 @ 131 (static)</td>
<td></td>
</tr>
</tbody>
</table>
Sprinkler Analysis of First Floor Warehouse Rack Storage

<table>
<thead>
<tr>
<th>Remote Area:</th>
<th>NFPA 13</th>
<th>Nominal Demand Per Owner Spec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warehouse Rack Storage, ESFR</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>K factor for QR wet pendant 160F</td>
<td>16.8</td>
<td>16.8*</td>
</tr>
<tr>
<td># sprinklers</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Sprinkler spacing (sf)</td>
<td>100 max</td>
<td>100 max</td>
</tr>
<tr>
<td>Minimum psi</td>
<td>35</td>
<td>35*</td>
</tr>
<tr>
<td>Sprinkler demand (gpm) Q=K√P (#)</td>
<td>1193</td>
<td>1193</td>
</tr>
<tr>
<td>Hose demand (gpm)</td>
<td>250</td>
<td>500**</td>
</tr>
<tr>
<td>Total demand (gpm)</td>
<td>1443</td>
<td>1693</td>
</tr>
<tr>
<td>Duration (minutes)</td>
<td>60</td>
<td>120**</td>
</tr>
<tr>
<td>Nominal water supply required (gal)</td>
<td>86,580</td>
<td>203,160</td>
</tr>
<tr>
<td>Water Supply Available on Site (gal)</td>
<td>600,000</td>
<td></td>
</tr>
</tbody>
</table>

* FM Data Sheet 8-9, for 14’ ceilings, K-factor, pressure
** Demand for hose flow and duration are double minimum requirements
Sprinkler Supply Curve for Warehouse Rack Storage

- Demand
  - 1784 gpm demand @ 96.8 psi

- Supply Curve
  - 1784 gpm supply @ 110 psi

- Capacity
  - better than 110%
Alarm System Description

- Non-coded addressable system with multiplexed signal transmission
- Equipment and systems are UL listed and FM approved
- Listed off-site central station
- On-site proprietary fire department

**Initiating Signals**
- Smoke
- Heat
- Manual
- Duct smoke
- Waterflow
- Supervisory
- Trouble

**Fire Alarm Control Panel**
- Identify Zone & Alarm type/group
- Identify Trouble and Supervisory Signals
- Operator Interface
- Switches & Control Relays
- Power & UPS

**Primary Actions**
- Alert occupants by strobe and voice com
- Notify Remote and Proprietary Stations
- Activate Smoke Dampers in Ducts
- Recall Elevators
- Activate Folding Fire Doors

**Secondary Actions**
- Notify Fire Department
- Notify Maintenance Contractor

**Alarm System Sequence of Actions**
Smoke Dampers

• Passive smoke control
• Located in HVAC supply/exhaust duct penetrations
  • between floors and fire rated barriers
• Combination fire/smoke dampers closure by
  • 165°F electric sensor thermostat (in place of fusible link)
  • Photoelectric type smoke detection
  • UL555S Leakage Rating Class: I
• When damper(s) close, smoke is isolated to the fire floor:
  • HVAC system enters smoke control mode
  • AHU’s maintain cooling maximum airflow, heating dampers are closed
  • Alarms activate and fans shutdown in affected alarm zone
  • Smoke concentration increases locally and spreads throughout floor as plume is pushed toward exhaust vents in other zones
  • Fire floor becomes pressurized as additional dampers close
Airport Terminal Building
Non-Mandatory Section

• IFC Chapter 20 Aviation Facilities
  • Ignition sources, housekeeping, fire department access and combustible/flammable materials
  • Aircraft being fueled shall be positioned such that any fuel system vents and other fuel tank openings are a minimum of 25 ft from buildings.

• Passenger areas in this building are less than 10% of floor and accessory to Group B

*Distance from aircraft and fuel vents to building*
Airport Terminal Building
Non-Mandatory Standard

• NFPA 415, “Standard for Airport Terminal Buildings, Fueling Ramp Drainage, and Loading Walkways”
  • Fire resistant structure and finishes
  • Remote HVAC intake and exhaust openings
  • Passenger areas protected as Ordinary Hazard Group 1

• Glazing NOT protected with water spray system
• Ramps do NOT slope away from terminal building with 1% grade

Ramp slope and low point catch basins
Performance Based Design Fire Selection

**Required Design Scenarios per NFPA 101 Chapter 5**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Smoke Detection time (s)</th>
<th>HRR at detection (kW)</th>
<th>Sprinkler Activation time (s)</th>
<th>HRR at Sprinkler Activation (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open Area Office Workstations</td>
<td>52</td>
<td>72</td>
<td>332</td>
<td>523</td>
</tr>
<tr>
<td>Blocked Egress</td>
<td>5</td>
<td>31</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Storage Room Stacked Chairs</td>
<td>48</td>
<td>58</td>
<td>209</td>
<td>608</td>
</tr>
<tr>
<td>Concealed Cabinets</td>
<td>96</td>
<td>47</td>
<td>341</td>
<td>386</td>
</tr>
<tr>
<td>Luggage Storage room</td>
<td>94</td>
<td>45</td>
<td>341</td>
<td>386</td>
</tr>
<tr>
<td>Warehouse Class I-IV Commodities Racks</td>
<td>131</td>
<td>144</td>
<td>385</td>
<td>805</td>
</tr>
<tr>
<td>Exterior Exposure Fuel Spill</td>
<td>N/A</td>
<td>N/A</td>
<td>∞</td>
<td>30,000</td>
</tr>
</tbody>
</table>

- DETACT Results used to estimate fire sizes and times for selection purpose
- Options Considered
  - Unfamiliar occupants: Stacked Chairs
  - Separated Area: Rack Storage
- Options Selected
  - Most likely for occupancy; Longest required safe egress: Office Workstation
  - Unique Exterior Exposure: Jet Fuel Spill
Performance Based Analysis-Office Fire
Occupant Characteristics & Pre-Movement Activity

- Familiarity with the building and emergency procedures is high in office areas
- Visitors accompanied by employee escort
- Committed to work activities
- Full occupant load 1,441
  - Speed (1.2 m/s)
  - 6% Population Disabled (.9 m/s)

- NIST study referenced for pre-movement time mid-rise office building

Assembly Area, 2nd Floor
Tenability
Performance Criteria

• Design objective: Maintain tenable conditions throughout the building during the required safe egress time for each area

• Performance:
  • Visibility beyond 4m for familiar areas (emotional effect)\(^1\)
  • Visibility beyond 13m for assembly (visitor) areas\(^1\)
  • CO concentration not to exceed 1000 ppm (average concentration at FED=0.3 for 11 minutes)\(^2\)
  • Temperature not to exceed 100°C in room of origin (tolerable for up to 12 minutes)\(^2\)
  • Temperature not to exceed 60°C in all areas of building (skin contact with metal)\(^1\)

\(^1\)Jin, T., SFPE HB 4th Ed, 2008
\(^2\)Purser, D., SPFE HB 4th Ed, 2008
Design Fire
Office Workstation

• Occupancy Specific
  • Interconnected modular furniture units
  • Electrical origin: overloaded power strip
  • Slow initiation, medium growth
  • Fuel available
  • Smoke travels to egress pathways
  • Significant queuing of evacuees at 3rd floor stairway entrance

• Geometry
  • Open office area on the 3rd floor (ventilated)
  • 50 ft x 90 ft space, 9 ft suspended ceiling
  • 53 workstations in area
  • Engineering style workstation
  • Groups of four with partition walls

*Workstation Large Scale Calorimetry at 180s with burner (NIST)*
Fire Model
Layout, 3rd floor Open Office

West Exit Stairway

Fire location
Photoelectric Smoke detector
K 5.6, 68°C Sprinklers
Exhaust vent
Supply vent 300cfm
Design Fire
Office Workstation

- Large Scale Office Furniture Fire Test Literature
- Fuel Properties
  - 4 modern workstations total mass 1086 kg
  - Materials lumped (59% Paper & wood; 41% nylon & polypropylene; 1% polyurethane)
- Smoke Yields
  - Soot 0.04 kg/kg
  - Carbon Monoxide 0.02 kg/kg
- Heat Release Rate Curve
  - Incipient stage for 3 minutes
  - Transitions to medium growth, t-squared
  - Peak HRR 2271 kW in 732 s

Workstation Heat Release Rate Test at NRIFD
(SFPE HB, 4th Ed, Figure 3-1.161)
FDS Simulation

- Pre-movement phase commences after first smoke detector activates (65 s)
- Steady state HRR after first sprinkler reaches activation temperature
Egress Simulation
Queuing Effect at Exit Stairs

Evacuation in progress
5 minutes after alarm notification
90 occupants waiting to leave 3rd floor
## Egress Analysis
### Methods for Required Safe Egress Time

**Simulation Times from Notification to Building Evacuation**

<table>
<thead>
<tr>
<th>Method</th>
<th>Detection time (min)</th>
<th>Delay Time (min)</th>
<th>Movement Time (min)</th>
<th>Total Evacuation (min)</th>
<th>RSET (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydraulic (Hand Calc)</td>
<td>0</td>
<td>2.5 max</td>
<td>7.9</td>
<td>10.4</td>
<td></td>
</tr>
<tr>
<td>Node (Hand Calc)</td>
<td>0</td>
<td>2.5 max</td>
<td>7</td>
<td>9.5</td>
<td></td>
</tr>
<tr>
<td>Pathfinder (Simulation)</td>
<td>0</td>
<td>(min=0,max=2.5, n=1.5, σ=1)</td>
<td>6.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Detection plus Pathfinder</td>
<td>1.1</td>
<td>(min=0,max=2.5, n=1.5, σ=1)</td>
<td>6.7</td>
<td>7.8</td>
<td></td>
</tr>
<tr>
<td>Detection plus 3rd Floor Only</td>
<td>1.1</td>
<td>(min=0,max=2.5, n=1.5, σ=1)</td>
<td>5.4</td>
<td>6.5 (3rd floor)</td>
<td></td>
</tr>
</tbody>
</table>
Results of FDS Simulation

• After 6.5 minutes
  • Occupants evacuated 3rd floor
  • Visibility at door to west exit stairway reduced to 4m
Results of FDS Simulation

• After 15 minutes:
  • Temperature remains below 50°C at 6ft above floor in all areas (100°C tenability limit)
  • Carbon monoxide does not exceed 30ppm (1000 ppm tenability limit)
  • Visibility below 4m only in room of origin
## Results

<table>
<thead>
<tr>
<th>TIME (s)</th>
<th>AVAILABLE SAFE EGRESS TIME (Visibility in exit pathway above 4m)</th>
<th>REQUIRED SAFE EGRESS TIME BUILDING</th>
<th>MOVEMENT TIME BUILDING</th>
<th>MOVEMENT TIME THIRD FLOOR</th>
<th>PREMOVTION TIME</th>
<th>DETECT TIME</th>
<th>IGNITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>65</td>
<td>210</td>
<td>253</td>
<td>174</td>
<td>65</td>
<td>150</td>
<td>65</td>
<td>65</td>
</tr>
<tr>
<td>210</td>
<td>389</td>
<td>253</td>
<td>174</td>
<td>65</td>
<td>150</td>
<td>65</td>
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<tr>
<td>389</td>
<td>468</td>
<td>253</td>
<td>174</td>
<td>65</td>
<td>150</td>
<td>65</td>
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</tr>
<tr>
<td>468</td>
<td>900</td>
<td>253</td>
<td>174</td>
<td>65</td>
<td>150</td>
<td>65</td>
<td>65</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TIME (min)</th>
<th>AVAILABLE SAFE EGRESS TIME (Visibility in exit pathway above 4m)</th>
<th>REQUIRED SAFE EGRESS TIME BUILDING</th>
<th>MOVEMENT TIME BUILDING</th>
<th>MOVEMENT TIME THIRD FLOOR</th>
<th>PREMOVTION TIME</th>
<th>DETECT TIME</th>
<th>IGNITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>3.5</td>
<td>6.5</td>
<td>7.8</td>
<td>65</td>
<td>150</td>
<td>65</td>
<td>65</td>
</tr>
<tr>
<td>3.5</td>
<td>6.5</td>
<td>7.8</td>
<td>65</td>
<td>150</td>
<td>65</td>
<td>65</td>
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</tr>
<tr>
<td>6.5</td>
<td>7.8</td>
<td>65</td>
<td>150</td>
<td>65</td>
<td>150</td>
<td>65</td>
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<tr>
<td>7.8</td>
<td>900</td>
<td>65</td>
<td>150</td>
<td>65</td>
<td>150</td>
<td>65</td>
<td>65</td>
</tr>
</tbody>
</table>
Performance Based Analysis

Exterior Fire

- Jet-A fuel spills from outboard wing tank vents 50L/minute
- Continuous flow for at least 5 minutes.
- Large spill area, unconfined, flow to catch basin.
- Ideal weather conditions; ignited by electric discharge or service vehicle.
- The building exterior areas are exposed.
- Occupants observe the fire and leave the balcony.
- Occupants inside the building do not experience fire effects.

Fuel spill fire location under wing near catch basin
Performance Criteria

• Radiation less than 2.5 kW/m² heat flux at floor level and on the balcony
  • Tolerable for greater than 5 minutes in order to allow occupants to re-enter the building.

• Radiation less than 9 kW/m² heat flux at glazing
  • Cracking but not breaking range is 3 to 16 kW/m²
  • Glass to fall out is range 70 to 110 kW/m²

• Surface temperature less than 60°C at exterior pane of glazing for the duration of the fuel fire.
  • Manufacturer’s thermal stress guideline for the exterior pane safety

1Jin, T., SFPE HB 4th Ed
2Cohen, J.D., Fire Management in WUI, 1994
3Shepard, D., Guardian, 2012
Performance Based Analysis
Exterior Fire

Point Source fuel spill fire model
Performance Based Analysis
Exterior Fire Heat Output

- Radiative heat output is a function of heat of combustion, fuel burn rate, spill area and fire diameter.

\[ \dot{Q}_r = X_r \dot{Q} = (0.21 - 0.0034D) \Delta H \dot{m}'' \infty (1 - \exp(-k\beta D))A \]

- \( Q_r \) (kW) = total radiative energy output of the fire
- \( X_r \) = radiative fraction, correlated function of pool diameter \( D \) (m).
  - Fit to a curve of experimental values. Sometimes assumed to be 0.3, but for large diameter fires, the radiative fraction decreases.
- \( A \) (m²) = surface area of burning fuel
- \( \Delta H \) (MJ/kg) = heat of combustion of fuel
- \( \dot{m}'' \) (kg/m²s) = burning rate of fuel
- \( k\beta \) (m⁻¹) = extinction coefficient and mean beam length corrector

Large pool diameter radiative fraction (Koseki, 1989)
Performance Based Analysis
Exterior Fire Heat Flux on Building

- Heat flux is a function of the heat output and distance of target from center of the flame.

\[ \dot{q}'' = \frac{\dot{Q}_r \cos \theta}{4\pi R^2} \]

**Point Source fuel spill fire model**
Performance Based Analysis
Temperature Effect on Windows

• Temperature rise is a function of heat flux, time and thermal properties of the material
  • Simple model used to represent double pane
  • Glazing is thermally thin
  • Safety factor of 2 applied to heat flux
  • Inside surface treated as adiabatic

Heat balance for glazing
Performance Based Analysis

Temperature Effect on Windows

- \( T (K) \) = temperature as a function of time \( t(s) \)

\[
T_{g(t+\Delta t)} = T_{g(t)} + (\Delta t/\rho c \Delta x)[2\alpha q_r - h_{out}(T_{g(t)} - T_{out}) - \varepsilon \sigma (T_{g(t)}^4 - T_{out}^4)]
\]

- \( h (kW/m^2) \) = heat transfer coefficient of natural convection of air
- \( \rho (kg/m^3) \) = density of glass
- \( c_p (kJ/kg K) \) = heat capacity of glass
- \( \varepsilon \) = emissivity of glass: 0.89
- \( \sigma (W/m^2K^4) \) = Stefan Boltzmann constant
- \( \Delta x (m) \) = thickness of assembly, neglecting the argon gap
- \( \alpha = 38\% \) absorption
- \( q_r \) = radiative heat flux doubled for safety factor

Diagram:

- First floor glazing temperature
- Glazing Thermal Stress Guideline
- Building evacuation time (RSET)
Design Fire Performance Results

<table>
<thead>
<tr>
<th>Level</th>
<th>Performance Criteria T (°C)</th>
<th>Surface Temperature at 5 minutes T (°C)</th>
<th>Surface Temperature at 8 minutes (RSET) T (°C)</th>
<th>Performance Criteria (kW/m²)</th>
<th>Heat Flux w/ Safety Factor of 2 (kW/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glazing</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>First floor 3 m</td>
<td>60</td>
<td>52</td>
<td>59</td>
<td>2.5</td>
<td>9</td>
</tr>
<tr>
<td>Second floor glazing 10m</td>
<td>60</td>
<td>50</td>
<td>56</td>
<td>2.5</td>
<td>9</td>
</tr>
</tbody>
</table>

- Heat flux does not exceed cracking/breaking limit for glazing
- Glazing temperature does not exceed manufacturer’s guidelines
- Ground personnel near building have heat exposure risk at 5 minutes
Summary

• Satisfies all prescriptive requirements.
• Exceeds prescriptive requirements for fire resistant finishes, construction, sprinkler density, water supply capacity.
• Occupant life-safety is improved
  • On-site proprietary fire department
  • Emergency preparedness program
  • FM Global standards for fire system inspection and maintenance
• Available safe egress time exceeds required safe egress time.
• Performance analysis indicates the building is a safe refuge for occupants for exterior fuel fire
Recommendations

• Non-mandatory standards for terminal building and fuel stall have not been achieved.
  • May limit the use of the building for future applications.
  • Large fuel spill fire may cause damage to the glazing.

• Upgrades will accommodate future use as a public terminal building and meet NFPA 415 standards
  • Re-grade three aircraft stalls to 1% and sloping away from building into a trench drain, leading to oil-water separator
  • Install heat detection and water spray protection at glazing that faces stalls on east side of building